DESIGN OF PRESSURE GARMENTS FOR HYPERTROPHIC SCAR TREATMENT

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ABSTRACT

Pressure garments constructed using a variety of elastic fabrics play a very important role in burn rehabilitation by helping to prevent or reduce the formation of hypertrophic scars. The method of manufacturing pressure garments was basically "cut-and-sew", and the garments were made either commercially or by the staff of the medical units of hospitals. Different compressions produced by the pressure garments for different groups of patients are typically achieved by selection of different kinds of elastic fabric and/or by adjustment of the pattern size. There is no agreed fabric and manufacturing specification with the result that many types of fabric and construction method are used to make pressure garments. The traditional manufacturing method used in Hong Kong is subjective and relies mainly on the experience of the therapists; garment fitting is critical and alteration on pressure garments is essential.

A brief account of the existing practice and the problems related to the design and manufacturing of pressure garments were reviewed in advance of commencing.

The author proposes a simple and more suitable method with the help of which it was possible to cut the pressure garments more precisely for the required compression. Based

on the principle of Laplace Law and using the fabric tension characteristics, the relation between skin-and-garment interface pressure, fabric tension and fabric curvature were examined by using a simple cylindrical tube model as well as on the limbs of a human body. The study was performed on 63 sets of tubular pressure garments and on nine tube models with size ranges similar to the limbs size of human adults. An equation $T = (A + B\ P_{human} / R)\ C$ was derived from the experimental results. A set of graphs was developed for recommending the correct measurement of prestretch pressure garments to the therapists for cutting and drafting of pressure garments. The effectiveness of the developed drafting method was evaluated by means of wearer trials.

The project included the investigation of size of fabric specimen and aspect ratio on the effect of fabric tension. The properties of four types of seams used on pressure garment construction, were studied and compared. The testing of seams carried out encompassed the breaking strength, breaking extension, seam slippage, elasticity and recovery, and seam thickness. The effect of seams and garment edges on the interface pressure was also examined.

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CHAPTER ONE : INTRODUCTION

1.1 BACKGROUND OF THE INVESTIGATION

Hypertrophic scars are thickened, hard areas of scarred skin which often become tumorous. They are commonly a result of thermal and chemical burns especially when the skin is destroyed beyond a critical depth. Functional and cosmetical disability can be quite marked depending on the site of injury and the extent of damage. This problem is a common occurence among the Chinese, not only is the extent of the hypertrophy more serious than in Caucasians, the hypertrophied scar in the Chinese either persists or the softening and flattening process with treatment is slow and may take over four years to be completed.

Pressure therapy has proven highly successful in preventing and controlling hypertrophic scarring after burn injury (Larson DL, 1971 & 1976) [1] [2], (Linares HA, 1976) [3], (Huang TT, 1978) [4], and pressure treatment based principally on the use of pressure garments is widely used in Hong Kong and many other countries. In addition to the use of external pressure, some other treatment methods for burn scars, such as by the injection of steroids (Kenalog) (Ketchum LD, 1971) [5], (Minkowitz F, 1967) [6] ; by surgical treatment (Druitt R., 1844) [7]; by the application of silicone products (Quinn K.J., 1985) [8]; and by radiotherpy (Peacock E.E., 1970) [9]; also have been utilized over the years. The application of silicon gel alone or applying it under pressure garments both are found effective in reducing hypertrophic scarring (Perkins K., 1982) [10].

In Hong Kong, thousands of patients are suffering from burn wounds each year. Pressure garments constructed using a variety of elastic fabrics play a very important role in burn rehabilitation. In general, the duration of rehabilitation after burn treatment is around twelve months, and a patient requires two to three sets of pressure garment each time. The average life expectancy of a pressure garment is two to three months, when the pressure garment loses its elasticity and loses its ability to exert the correct pressure on the patient. The pressure garment then has to be replaced. The durability of pressure garments is due to many variables , such as donning procedures, care, environmental factors, the patient's occupation and his working environment etc.

The Government hospitals of Hong Kong have been using pressure garments in the treatment of hypertrophic scars since 1976, and the pressure garments are all locally made in the Occupational Therapy Departments of the various hospitals, but it was found that there has not been much change in the construction method nor the fabric used since the early 1980's. In the past few years, the author has researched in the area 'The properties and comfort of pressure garments' (Yip Ng S.F., 1990) [11] working in collaboration with the medical team and the Occupational Therapy Unit, Prince of Wales Hospital of Hong Kong. The investigation falls into two categories: physical testing of the properties of the elastic fabrics used for making pressure garments; and subjective testing, to measure the wearers' opinion and preferences for the different fabrics. The study results indicate that all warp knit fabrics for the test are very good in air-permeability as well as resistance to abrasion, and their elastic recovery is affected by the amount of stretch and by repeated washings. It was also discovered that existing pressure garments used in the hospitals of Hong Kong are far from satisfactory, particularly on the manufacturing and design aspects as they require frequent adjustment and repair.

The fitting of the existing pressure garments is far from ideal as many hospitals cut their own pressure garments based on the techniques using an estimated percentage reduction at the pattern stage and detailed adjustment is made by fitting on the patient. As alteration of the garments is almost invariably necessary, a lot of money and time is wasted, and also the patients will suffer.

As the author had previously studied the properties of the different elastic fabrics related to their suitability for making pressure garments , the aim of the work reported hereafter is to develop a more suitable drafting method to work out the percentage of reduction needed in the making of pressure garments. Although the actual skin-garment interface pressures cannot be measured directly from the garment, it should be possible to predict the pressure from a measure of the tension developed in the fabric of pressure garments and the geometry of the body surface.

If rational draft rules for pressure garment contruction can be formulated, then the existing problems with garment drafting and subsequent size alteration can be virtually eliminated.

Moreover, there are other areas of pressure garments construction which warrant attention, such as the stitch and seams, for they have marked impact on the comfort and durability of the pressure garments. Comments from the patients and occupational therapists have indicated that discomfort and defects arose in the seam zone, and it is evident that research into the seaming methods is required if these problems are to be eliminated.

1.2 AIM

To assist the occupational therapist in designing the pressure garment for burn patients.

To determine appropriate garment parameters needed for the manufacture of pressure garments that give the required constant correct pressure and are comfortable to wear.

1.3 OBJECTIVES

1. To provide background information on the various problems related to the design and manufacture of pressure garments.

2. To study the relationship between the tensile properties of the two commonly used elastic fabrics, the fabric curvature, and the pressure exerted on the surface of human limbs by pressure garments.

3. To conduct physical tests to measure the tensile properties of the elastic fabrics used for making pressure garments and also the pressure exerted on the surface of the human body.

4. To develop drafting rules for pressure garment construction.

5. To study the various seaming methods for the manufacturing of pressure garments.

6. To make recommendations for the selection of stitch and seams for the making of pressure garments.

1.4 RESEARCH METHODS

The study commenced with a survey of relevant scientific literature and present clinical practice. A review is made on the existing practices in making up of pressure garments as well as the problems related to the design and manufacture of pressure garments.

In order to obtain more information on the cutting and seaming techniques of making pressure garments, contacts were made with relevant professionals including occuptaional therapists, manufacturers of pressure garments, and related professional institutes.

Based on information gathered, theoretical and experimental investigations are designed to study the relationships between pressure produced, fabric curvature, and the wale tension of the fabric used to manufacture the pressure garments.

A series of laboratory tests was carried out in the Institute of Textile and Clothing, Hong Kong Polytechnic University, for the comparison of the properties of the seams used for making pressure garments. Such physical testing included breaking strength of seams, seam slippage, seam elasticity and recovery, needle damage, seam thickness, and also their effect on skin-garment interface pressure.

Using the analysed research data, rules for garment design and manufacturing are produced to improve the fitting and clinical effectiveness of pressure garments.

Wear trials on volunteers were carried out to evaluate the rules derived from the experiments. The results of the wear tests were analysed and recommendations made on further development work.

CHAPTER TWO - REVIEWS OF SUBJECT AREAS

2.1 EXISTING PRACTICES IN MAKING UP PRESSURE GARMENTS

There are two types of pressure garments currently used:

(1) Garments which are made from firm elastic fabric containing Lycra. Several types of Lycra fabric can be used, mainly the warp knit powernet or sleeknit, the different levels of elasticity and strength of the materials giving varying degrees of fabric tension, thus inducing different degrees of pressure on patients.

(2) Garments which are made in "Tubigrip" - a weft knit cotton elastic material with rubber yarn laid in horizontally, manufactured in tubular lengths of different diameters.

Many doctors and therapists have found that the Lycra garments offer firmer pressure and last longer, whereas Tubigrip garments have greater stretch tolerance and require fewer measurements for proper fitting, which makes them more suitable for the initial stages of treatment, particularly for growing children.

Pressure garments are either made available as ready-to-wear garments, or are made according to the individual measurements of the patient. The ready-to-wear variety are made both in Lycra materials and in Tubigrip, whilst the made-to-measure garments are constructed from Lycra materials in the main.

2.1.1 Ready-to-wear Pressure Garments

Ready-made garments may be purchased by hospitals from commercial manufacturers. Such garments, made from both elastomeric fabrics or Tubigrip are generally used for preliminary treatment before custom-made garments can be provided.

The early use of pressure garments can be beneficial for the patient in terms of the rehabilitation process. The custom-made garments require time for measuring, ordering, and preparation, and so the delivery time for the custom-made pressure garment can take as long as three weeks from order to supply. Therefore, as soon as the wound heals, the ready-to-made pressure garment can be used to maintain a low-level of hyphertrophic scar development until the custom-made elastic pressure garments can be used.

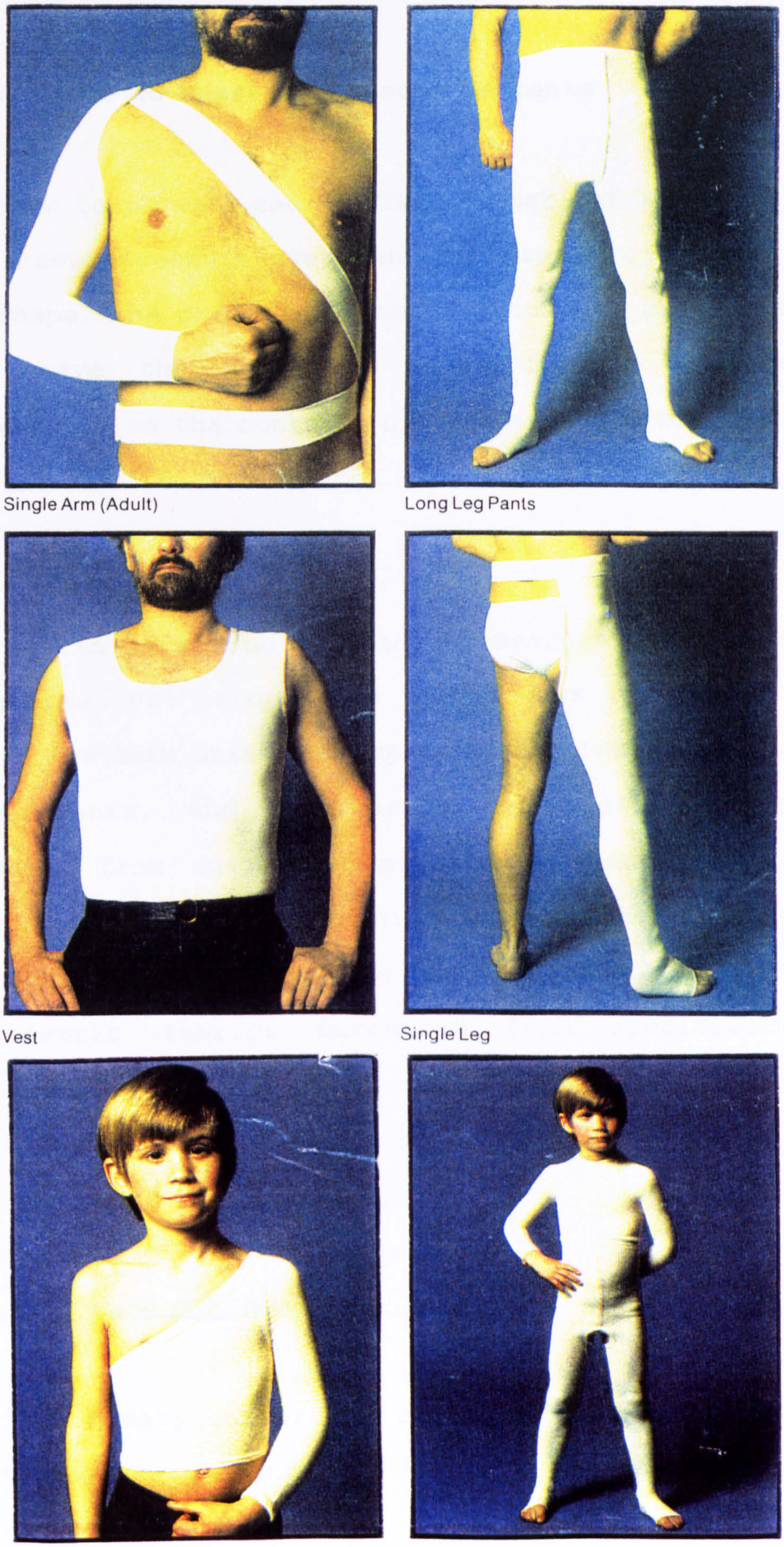
Sometimes, elastic bandages are used in an attempt to provide pressure in the early stages of treatment. These are applied in a spiral overlapping method to wounded surfaces, but the elastic bandages often slip, bunch up or constrict, and an even pressure cannot be maintained: these are therefore used mainly for short periods or temporary applications.

As the number and size of unhealed areas decrease, tubular elastic bandages may be applied to the extremities. Tubigrip, (a tubular support bandage manufactured by Seton Products Ltd. Oldham) is commonly used. It is made in a variety of diameters and it fits the trunk and extremities of all ages easily. Tension guide (see Appendix I) is used to help the therapist to select the appropriate fit. The Tubigrip material has a wider stretch tolerance and is useful at the early stages of treatment when body dimensions are changing or the patient cannot tolerate the extra pressure. It is good to use Tubigrip to apply pressure to selected body areas while allowing the remaining burned areas to heal sufficiently to permit measurement for long-term pressure garments. The hospital can stock various sizes of Tubigrip so that it is readily available as the patient's healed and unhealed areas dictate.

A range of Tubigrip ready-made pressure garments is also produced by commercial companies. They are designed to fit the "average" body and are sold in only a few different sizes. Simple alterations may be necessary to the ready-to-made pressure garments, perhaps, for example, to the length of retaining straps in the single arm or leg garments. Examples of Tubigrip pressure garments are shown in Fig.2.1. Sometimes, the patients are treated with Tubigrip garments not only as a temporary dressing, but as a definitive compression garment when the patient is allergic to the synthetic Lycra fabric used for making the specially measured garments.

Another kind of ready made pressure garments made of Lycra material is produced by the Jobst Company. These are called "interim care garments", and are made similarly to the custom-made pressure garments, but the material used is lighter in weight and is more comfortable, and they are available in a range of standard measurement. The comfort of the interim care garments make them particularly suitable for the newly healed, sensitive skin.

Since ready-made pressure garments represent a temporary form of dressing, they are typically produced for use at the early stages of rehabilitation. They also instil psychological and physical preparedness for the continuing use of custom-made garments by the patient.



Single Arm (Adult)

Long Leg Pants

Vest

Single Leg

Single Arm (Child)

Sleeved Vest/Long Leg Pants (Child)

Fig. 2.1 Tubigrip Pressure Garments

(Ref: Promotional material of the manufacturer, Seton, U.K.)

2.1.2 Made-to-Measure Pressure Garments

In order to provide each individual patient with the correct continuous pressure over the scar area, regardless of size and shape, the pressure garments should be made to measure. They have the advantage of conforming precisely and comfortably to the contours of the patient's body, and hence provide maximum benefit.

The system of making the made-to-measure pressure garments in general use is operated in two ways : First, the staff within the burn units of hospitals take individual patients' measurements, and then order the custom-made pressure garments from specialist pressure garment manufacturers. Second, staff of the burn units of hospitals take individual patients' measurements, and produce pressure garments from elastomeric fabrics purchased from specialist fabric producers.

2.1.2.1 Made by Commercial Companies

There are many commercial companies manufacturing custom-made pressure garments for the burn patients. For example, Jobst, Pan Med, Biocepts, Recovery Garment Center, and Mydron Specialties Company (see Appendix II).

Most specialist pressure garment maufacturers, purchase elastomeric fabrics from specialist fabric producers. For example, Pan Med purchase several types of elastomeric fabrics containing Lycra for the manufacturing of pressure garments from a U.K. fabric supplier named Penn International. Their choice of material is dependent on the therapist's evaluation of the patient's requirements, and mainly based on the experience of the specialist working in their company.

The established specialist pressure garment manufacturers like the Jobst Company have developed bobbinet and powernet fabrics specially used for the construction of pressure gradient garments.

Patients are measured for the garments by the therapists in hospitals when their wounds are almost fully healed. In order to fit each patient accurately so that adequate pressure can be consistently maintained over the burned scar areas, the circumference of every part of the body is measured at very short intervals.

Measurements for garments can be made using a patented tape-measure provided by the commercial company, and accurate longitudinal and circumferential dimensions are guaged at short intervals, e.g. every one-and-a-half inches along the arms and leg (See Appendix III). Different order chart are supplied by garment manufacturers for easy record of measurements and manufacturing instructions. Special measuring forms with measurements that are quoted against a simple number reference (see appendix IV) have also been designed for easy use by overseas customers with access by a telex or fax machine, all revelant measurements may be taken by the therapists and sent back to the commercial companies to eliminate any delay due to posting.

Dependent on the characteristics of the elastic fabric, simple patterns are adjusted to allow for stretch in garments in order to produce the required compression on patients. Special drafting equipment has also been designed by a commercial company to shorten measurements by between 5 per cent and 10 per cent, so as to give the required pressure for the garments while reading the measurement directly from the measurement charts. The established specialist pressure garment manufacturers have developed their own, standard engineering formulae to determine the size of the pattern and subsequently create a gradient pressure within the garment.

Garments are subsequently constructed from the individual patient measurements taken as per the physician's prescription by the commercial company concerned. Then the patient will go to the medical unit again for checking and fitting of the pressure garments. The assessment of the garments performance is subjective, most often, with two fingers of the therapist being inserted between the garment and the skin to check for tightness, or the seam of the garment is gripped and pulled away from the body to check the resistance. Patients are followed up at the hospital at regular time intervals; for example every five or six weeks; when they are remeasured and the perfomance of garment are reassessed.

Fittings are provided to ensure comfort and problems concerned with itching are also assessed. If the fitting of the garment is found unsatisfactory, it will be returned to the manufacturer for alteration.

The garment fitting and size alteration is very important in the application of pressure garments, almost all the commercial speicalist manufacturers provide the garment alteration service to their customers, but it takes time to sent the garment between the commercial companies and the hospitals; especially when they are far apart from each other. There are small commercial companies like the Recovery Garment Center in Canada, they can provide 'on the spot' alteration service: this means that at the time of delivery, they will have the sewing machines with them and will be able to make any necessary adjustments. This kind of alteration service enables them to do a very personalized fit on the day of delivery. The garment will be taken back to their center for alteration only if major changes are required.

2.1.2.2 Made by the Staff Inside Medical Unit

Although commercial making-up services are available, some medical centers and hospitals favour the system of producing their own pressure garments in the occupational therapy department.

In Hong Kong, pressure garments are all locally made in the occupational therapy departments of the various hospitals . The procedures currently followed in Hong Kong for making and fitting pressure garments are similar to many hospitals in the U.K., as follows:

Patients are carefully measured for the required measurement in the similar way as taking the measurements of garments for the commercial maunufacturers as described 2.1.2.1.

Fabric is cut according to a special pattern made to fit each patient, each has about 15 per cent taken off the circumference measurement so that tension is induced in the garment. Very often, there is a small reduction (for example, 10 per cent), at the top and bottom of the garments to avoid discomfort or oedema. Then, the whole pressure garment is sewn by the therapist or medical staff inside the hospital.

Just like the fitting of commercial made pressure garments, subjective assessment of tension is made when the garment is fitted on the patient, he or she being consulted about the comfort of the item. If insufficient tension is found in certain areas, adjustment may be made by sewing in a 'tuck' at the seam. All the patients are examined for progress in a clinic run jointly by the medical doctors and therapists in charge.

Fabric used to make pressure garments in Hong Kong is made from a synthetic elastomeric yarn with Lycra; this is also used widely in the underwear manufacturing industry. The fabric is relatively inexpensive and there is some variation on the material supplied each year as, it is bought locally as 'end of run' stock or as 'excess to requirements'. Also because each hospital sends their own representives to the fabric supplier to select the fabrics for their own hospital, the fabrics used at each hospital may vary.

Three types of elastomeric Lycra-net fabrics having different strengths are purchased for the hospital each time, since patients in the differing phases of the healing process need pressure garments providing different levels of pressure. In general, children or patients with newly healed wounds will be offered the garments made of the softest and most comfortable material, while the stronger material will be used on adults, who require higher compression for their treatment.

However, each hospital has its own operating system, and many hospitals in the UK making the pressure garments use only one kind of Lycra fabric each time. Different degrees of compression produced by the pressure garments for different groups of patient can be achieved by adjustment of the pattern size and the fitting of pressure garments. And unlike the fabric purchasing system in Hong Kong, some hospitals in U.K. purchase the same kind of Lycra fabric from the same fabric supplier as the commercial specialist garment manufacturer.

2.1.3 The Making Up of Pressure Garments

The pressure garments made by commercial manufacturers are made to a very high standard, different types of stitch and seams being used on different parts of the garments for different requirements. For example, the cut edges of the garments are neatened by means of a three-thread overlocking stitch (B.S.504); flat seams are used to reduce the thickness of the seam allowance of the two joined edges; and the stitch used to join the seams is either stitch B.S.503 or a covering stitch B.S.606. A two thread zig-zag lockstitch B.S.304 is also used for sewing the Velcro or rubber band onto the garments. The simple lockstitch B.S.301 is used mainly for sewing zippers in position.

However, many hospitals still use only one type of zig-zag lockstitch B.S.304 for the construction of the whole garment. The cut edges of the seams are left on the outside of the garment to prevent irritation of freshly healed skin, and the seams are of the garments are not as smooth and tidy as those found in commercial counterparts. Domestic zig-zag lockstitch machines are used for seaming. This is primarily because the use of one type of sewing saves money and space, and reduces the requisite level of production skill.

In the hospitals of Hong Kong, the conventional zig-zag lockstitch B.S.304 has been used for sewing the pressure garments for many years, until recently they started to use the overlocking stitch B.S.503 for the seaming of the main parts of pressure garments in order to improve the smoothness and comfortability of the seams.

The majority of pressure garments are fastened by means of zipper and Velcro fastenings. The fastenings used must be long enough to enable the patient to don and doff the garments easily, and the location of the fastenings is important to the design of the garment relative to the wound location. Regardless of whether zips or Velcro are used in the pressure garments, fastenings should not be placed on the wound area, neither should the compression and comfort of the pressure garments are affected.

2.2 THE PROBLEMS RELATING TO PRESSURE GARMENTS

Based on the information collected from previous research, it is concluded that some problems are related to the design and manufacturing of pressure garments.

2.2.1 Fabric

The existence of many problems in the techniques of pressure therapy using pressure garments are well identified by the work of Cheng and his colleagues (1983) [12]. Many doctors and occupational therapists in both U.K. and H.K. pointed out problems associated with the fabrics currently in use. Most of them commented that the stretchability of the fabric is unidirectional, and such a characteristic is acceptable for making pressure garments on nearly cylindrical surfaces such as the limbs and trunk, but causes major problems when fitting a more nearly spherical shape such as the head.

The elastic deterioration in the Lycra fabric is another major problem and most doctors and therapists criticized the fact that the tension of the fabric is time-dependent, so that slackening is bound to occur in pressure garments after a period of wear.

It was also found that the fabric was stiff and not smooth enough. The non-absorbing properties of the fabric gave discomfort to the patients, especially in hot or humid conditions. In some cases, patients were found to be allergic to the Lycra materials.

The natural rubber of Tubigrip material is better than the Lycra net in terms of elastic deterioration, but the rubber elastic elements are relatively sparse and thus insufficient tension is developed. Also line marks are caused on the skin. The cotton-base material, though absorbant, occludes the skin and is not so acceptable in a hot and humid climate.

From the work of previous research, it was noted that many types of elastic fabrics are used for making pressure garments, but none available in the commercial market is specially designed for this purpose. In addition, little information and no standards have been discovered concerning the required properties of fabrics for pressure garment applicatons. A long term solution would be the development of a superior fabric to fulfil the requirements of the criteria identified. A less time-dependent elastic fabric is needed, which can exert the required compression for clinical treatment, yet is reasonably comfortable in wear.

2.2.2 Design and Sizing

It is thought important that the design of a pressure garment should encourage the maintenance of the required pressure over the wounded surface.

The existing pressure garments are found to be undesirable because: many hospitals cut their own pressure garments using approximations of percentage reduction of pattern dimensions; for example, 15% or 20 per cent is taken off from the circumferential body measurement; the size of pressure garment being then adjusted by fitting on patients using subjective criteria. As alterations on the pressure garments are almost invariably necessary, a lot of time and money is wasted, and the patients will suffer consequently.

According to the Laplace Law, the pressure developed on a cyclindrical surface is directly porportional to the tension (and thus to the stretch, in the garment) and is inversely related to the radius of the curvature.Therefore in order to achieve effective and comfortable pressure garments for the wearers, rather than being based on an estimation in pattern cutting and adjustment of the sizes by fitting, for different parts of the body with differing radii of curvature, variations in the percentage to be deducted from the body measurements must be carefully calculated according to the different fabric elastic characteristics.

Even though the established specialist pressure garment manufacturers such as Jobst and Pan Med have claimed that they have developed their own standard engineering formulae to determine the size of the pattern to create a gradient pressure within the pressure garment, no commercial company is willing to supply details of the drafting rules to improve the fitting of pressure garments made by individual hospitals.

2.2.3 Seaming and Fastening

In view of the comments from both the patients and medical specialists, it was noted that problems are also encountered with the seaming of the pressure garments, Many pressure garments are made with bulky and rough seams which are neither durable nor comfortable. A majority of them pointed out that the pressure is localized and increased in the seam areas, and that line marks are commonly found on the skin as a result of seam impression. Some patients identified the seam area as significantly contributing to itching problems.

The strength and extensibility of seams is found undesirable in many cases, patients complained that some parts of the seam had been found to be broken after the pressure garment had been used for two to three weeks, and the seam had broken during the donning of the garment.

Many doctors and therapists responded in similar fashion to patients concerning the thick and bulky nature of garment seams, espeically to the seams constructed by the zig-zag lockstitch B.S.304 inside the hospitals. Even though the seam allowance of such kind of seams were turned out to the right side of the garments, patients still feel very uncomfortable when some part of their body rubbed against the seam.

Most pressure garments made by the staff inside hospitals do not have a very tidy and neat finish, riding up or sliding down of the waistline of pressure garments was always happened due to the absence of an appropriate trimmings such as rubber banding, attached to the hemline of the garments.

With regard to the Velcro fastenings, most of them agree that the rigidity of the Velcro reduces the stretchability of the fabric, thus greatly affecting the compression and comfortability especially when the Velcro is applied onto a part of a garment of small diameter. Both the Velcro and the zipper were said to create uneven pressure areas in the case where no padding was inserted beneath the fastening.

The stitch and seams used for the sewing of pressure garments should be compatible to the material being sewn both in extensibility and durability. They should be smooth and tidy, with minimum roughness and bulkiness, and cause no irritaiton on skin nor affect the pressure interface between the pressure garment and the skin.

2.2.4 Pressure Monitoring

The existing method of checking the fitting of pressure garments is in a basically subjective manner that is completely dependent on the experience of the therapists. It is difficult to ensure the correct pressure gradient without some measurements of pressure.

The transducer for monitoring the interface pressure produced by pressure garments must be able to function accurately within a very low pressure range, for example from 0-35mmHg. Such pressure range is required because that is the normal pressure range for clinical effectiveness of scar treatment. And in order not to distort the surface at the curved interface or affecting the accuracy of the pressure measured, the transducer must be small and thin, and also flexible enough to be used on curved body contours.

It is more ideal to have a more effective device for monitoring the static pressure as well as the instantaneous interface pressure variations with limb movements.

Improvements to pressure garments could be carried out more easily in a more reliable and objective manner if an effective pressure monitoring equipment is available. Unfortunately, even though there are many types of commercial pressure transducers for measuring pressure of different purposes, there is still lack of an appropriate transducer specially design for pressure garments.

2.3 SEAMING CRITERIA OF PRESSURE GARMENTS

After reviewing the various comments of the patients and relevant professional bodies, it is concluded that the seams of pressure garments should possess the following properties for both clinical effectiveness and the comfort of the patients, namely:

a) Seam Strength

As pressure garments are tightly fitted, and to be worn by patients continuously, night and day, the seams selected for sewing the pressure garments should be strong enough to resist high transverse force over a prolonged period of time.

b) Seam Stretchability

The stretchability of the fabric being sewn could not be restricted by the seams. A good elastic seam is required for body movement especially when wearing the pressure garments. The stitch and seams used for the sewing of pressure garments should be compatible to the material being sewn in extensibility.

c) <u>Fabric Damages/Maintain Fabric Structure</u>

The application of seams should cause no damages to the structure of the sewn fabric. The joined edges of the fabric components should be held securely by the seam and needle damages of any kind should be avoid or reduced to the minimum.

d) <u>Durability</u>

The seams used on pressure garments should be strong and durable to resist the daily wear and tear, and its properties should be maintained after multiple washings, so that the pressure garment can last for a period of few months which is the general life expectency of a pressure garment.

e) <u>Comfort</u>

A seam should be smooth and soft, with minimum roughness and bulkiness, and cause no abrasive nor allergy problems over the fragile skin in patients.

f) <u>Clinical Effectiveness</u>

In order to produce an evenly distributed pressure over the scarred area; the seams used for the sewing of pressure garments should not affect much on the pressure interface between the pressure garment and the skin.

g) <u>Appearance</u>

A neat and tidy seam made in matching color could help the pressure garment be concealed more easily under the covering garments. A badly constructed seam will make the pressure garments looks more obvious and thus less acceptable by the patients.

h) <u>Sewability</u>

If the construction of the seam is complicated, and/or the sewing process is difficult to handle, it would be difficult to control the accuracy of the garment measurement, and also will waste a lot of time and labour to complete the manufacturing process.

i) <u>Machinery</u>

The cost and maintenance of the machinery required must be considered during the selection of the seaming method. When different kinds of stitch are involved in the construction of a pressure garment, then more money and space are required for different machinery, and a higher level of production skill is also needed.

CHAPTER THREE : ENGINEERING PRINCIPLES IN THE MAKING UP OF PRESSURE GARMENTS

3.1 INTRODUCTION

3.1.1 Introduction

With reference to chapter two, the cutting and fitting of pressure garments was found to be far from satisfactory. It would be better if we could develop a set of draft rules for constructing patterns that will produce effective and comfortable pressure garments, rather than just estimating the dimensions in pattern cutting and adjusting them later during fitting. If such draft rules for pressure garment construction can be formulated, the extra problems with garment fitting and subsequent size alteration can be considerably reduced.

Although the actual garment-scar interface pressures cannot be measured from the physical testing of the fabrics, it should be possible to work out the size of the prestretch pressure garments to result in a given pressure over the circumference of a nearly cylindrical body surface by calculations based on the Laplace Law and using the fabric tension characteristics.

According to the Laplace Law, the pressure developed on a curved surface is directly proportional to the tension (and thus to the stretch) in the garment and is inversely related to the radius of the curvature. The estimation of interface pressure based on this theory is attempted by calculation in Section 3.2.1.

As the two main variables to be considered in determining the skin-and-garment interface pressure are : tension of the fabric and the curvature of the interface surfaces, the relation between pressure, fabric tension and fabric curvature will be examined by using a simple cylindrical model and also on the limbs of a human body. The values of compression obtained from garment samples applied on a cylindrical model and the limbs will also be compared.

3.1.2 Selecting Fabric Samples for the Study:

As no commercial fabrics are specially designed for pressure garments, a number of different stretchable fabrics (mainly warp knit Lycra net materials) are used for the manufacturing of pressure garments both by the commercial manufacturers and the therapy units of hospitals. In the previous research work (Yip Ng S.F. 1990) [11], six different fabrics which are all currently used by the hospitals in the U.K. and /or Hong Kong were compared for their suitability for making garments. Based on the results of the study, two of the fabrics tested which were of comparatively good serviceability were selected for further investigation in this part of study.

These two fabric samples #28432 and #25034 were obtained from Penn International- a major manufacturer in U.K. which supplies elastic fabrics to many hospitals and companies for the production of pressure garments. Details of fabrics are described below with accompanying samples.

Fabric No. 1 : - Cotton Sleeknit #28432
Gauge : Raschel warp knitted on 56 gauge
Fabric Weight : 270 g per sq. metre
Composition : 56 dtex nylon ; 480 dtex elastane and includes 16% of 100 Nm cotton
Breaking Load : 58 kg (lengthway); 75 kg (widthway)
Breaking Extension: 360% (lengthway); 280% (widthway)

Fabric No. 2 : - Powernet #25034
Gauge : Raschel warp knitted on 56 gauge
Fabric Weight : 220 g per sq. metre
Composition : 67 dtex nylon and 470 dtex elastane
Breaking Load : 60 kg (lengthway); 48 kg (widthway)
Breaking Extension: 380% (lengthway); 320% (widthway)

3.1.3 Selection of Measuring Pressure Device:

In order to check the validity of any theoretical calculation of skin-garment interface pressure, it is necessary to be able to make resonably accurate experimental measurements of this pressure. Some sort of interface pressure transducer is required.

In choosing this interface pressure transducer, certain specifications should be fulfilled (Bader D.L. 1982) [13]. Foremost, its presence must not affect the parameter being measured.

The interface pressure required for maximum therapeutic benefit does not appear to be accurately known. Pressures commonly used are however in the range 10mmHg to 35mmHg. In this study a wider range would be desirable so the transducer selected should have a range of at least 5 to 50mmHg with at least ±5% accuracy or a resolution of at least ± 1mmHg.

As the surface of the body is highy contoured, it is a prerequisite that the transducer must not distort the surface at the curved interface and, to achieve this, the transducer itself must be flexible, adapting its shape to that of the anatomical site . It will be ideal to have a transducer which is robust, but flexible enough to be used on curved body contours.

Another point to be considered upon the selection of the transducer for this study, is the size and the thickness of the transducer. When a transducer is placed on the surface of the skin, and the skin is compressed, via the transducer, the transducer is thus said to be at an interface. However, its presence modifies the mechanical properties of the skin and also affects the accuracy of the pressure measured. The effect of thickness-induced perturbation by various transducers placed on skin has been reviewed by Ferguson-Pell (1977) [14], his work clearly indicated that the perturbation due to the transducer is lower when the ratio of the transducer radius to thickness is higher. Because of these reasons, the most suitable transducer for measuring skin-and-garment interface pressure should be as thin as possible.

By the literature review of Ferguson-Pell and et al (1976) [15] on various pressure measurement devices , such as electropneumatic, pneumatic, capacitive, and resistive techniques, the use of an orthotic device is only one can meet the specification demanded of an interface transducer and achieves suitable performance in terms of sensitivity, lineraity, negligible hysteresis, and temperature independence. It also has the obvious advantages of being thin and flexible, and it is unaffected by the chemical environment encourtered in the clinical situation (Bader D.L.) [16].

After extensively reviewing and considering the requirements of the study, it was decided to use the Oxford Pressure Monitor MKII (Talley Group Ltd.) for the investigaion of the interface pressure between the skin and the pressure garments.

The Oxford pressure monitor MKII is one of the few commercial interface pressure sensors which meet the requirement of the study. It is a microprocessor controlled monitor for measuring the patient orthotic interface. It was primarily designed to monitor the pressures between skin tissue and the support media for chair or bed bound individuals, or indeed any application in which the pressure range could be expected as 0-240 mmHg, such as the pressure between support hosiery and the limb.

The principle of operation of the Oxford Pressure Monitor is similar to the Denne guage as described by Crewe in 1985 [17]. It employs a pneumatic principle to monitor the pressure continuously in any of a matrix of 12 cells. The sensor cell of the pressure monitor was modified to allow a deflated bag to be introduced at the patient interface. A volume of air was then injected into the bag via a three-way tap, and the pressure measurement obtained. It uses the minimum injected volume of air to measure an applied pressure, and does not appreciably deform the interface under investigation.

The applied pressure was monitored while air is introduced into the pressurizing system at a constant rate, as controlled by high pressure pump and a needle valve. The pressurizing system was divided into three distinct phases by O'Leary and Lyddy (1978) [18] . Initially the pressure in the system increases linearly up to the applied pressure (phase A). During this phase the bag remains flat at the interface and the incoming air only pressurizes the connecting air lines. As the applied pressure is reached and exceeded, the bag starts to inflate, the system volume increases and the rise in pressure is smaller for a given injected volume of air (phase B). In the final phase the slope of the curves increases dramatically, as the bag has become fully inflated and the resulting tension in its wall resists further changes in volume.

The design of the pressuring system of the monitor is programmed to detect the point of change-over from phase A to phase B, when the system pressure equals to the applied pressure and the bag starts to open. A static measurement of system pressure is obtained at that instant of time by using a semiconductor strain-guage pressure transducer.

However, as the size of the sensing cell of MKII is already 2cm x 2cm, and it is made of plastic layers of certain thickness, the pressure monitor was found unsuitable to measure interface pressure between rigid surfaces or the interface surface of very high curvature. The monitor functions accurately at the range of radii of curvature normally encountered on the limbs, but measurement become inconsistent when the interface curved surface is smaller than 3cm radius. This is due to the design of the pressurised system of the pressure monitor; the air flow will become unsteady when the sensor cell is bent to certain high curvature, and thus unsteady pressures arise as a result of the turbulent flow of air into the plastic sensing cell.

3.2 RELATIONSHIP BETWEEN FABRIC CURVATURE, LONGITUDINAL TENSION, AND INTERFACE PRESSURE OF PRESSURE GARMENTS

3.2.1 Theoretical Estimation of Interface Pressure for Pressure Garments in Terms of the Tensile Behaviour of Fabric

The pressure produced by a curved membrane under tension can be shown to be :

$$P = (Tx / Rx) + (Ty / Ry)$$

where P = Pressure Produced

Tx = Tension per unit length in the x direction

Rx = Radius of curvature in the x direction

Ty = Tension per unit length in the y direction

Ry = Radius of curvature in the y direction

(see Appendix 5 for details of how the formulae is derived)

If we use SI units, with T in Newton/metre, and R in metres then P will be in Pascals.

If the membrane forms the surface of a cylinder one R will become infinitive and the formula will become :

$$P = T/R \quad \text{(sometimes called Laplace Law)}$$

If, on the other hand, the membrane forms part of the surface of a sphere $Rx=Ry$ and the formula reduces to :

$P = 2T/R$ (The formula for the pressure inside a soap bubble)

Whichever of these three formulae we use, if we wish to calculate P we need to know the appropriate values of T (Tension/unit length) and R (The radius of curvature).

R can usually be measured directly, but problems can arise if the membrane curvature is not equal to the limb curvature, or the membrane distorts the limb, thus alterating its curvature.

T on the other hand cannot easily be measured directly but can be obtained from Load/Extension curves of the membrane as the extension is usually measurable. Thus if we can measure R and the membrane extension and we know the Load/Extension curve of the membrane we should be able to calculate P.

The tensile properties of the fabric determines the amount of compressive force which can induce on the skin-and-garment interface curve surface. For different elastic fabrics with different tensile properties, cut-strip tests were used to measure the tension force of fabric under different fabric extensions.

The fabric specimens (#25034 and #28432) were cut in size 5cm x 15cm. An Instron Tensile Strength machine (model 1026) was used with gauge length 10cm, clamp width 5cm (flat faces); and the tension load cell scale was 5Kg. In all cases the specimens were extended at constant rate of 200mm/min. The tension force is measured when the fabric strips are extended by 5% - 60% (at 5% intervals) in a lengthway direction.

Based on the tension (gf) data recorded (see Table 3.1), if the diameter of the cylindrical surface is known, for example, if we assume the surface curvature to be 0.1 meter in diameter, the possible interface pressure created by the fabric compression can be worked out (see Table 3.2).

Stretch Percentage	Fabric #28432	Fabric #25034
5	150	150
10	275	265
15	385	365
20	490	465
25	600	560
30	685	655
35	780	730
40	880	800
45	970	880
50	1065	950
55	1155	1035
60	1250	1100

Table 3.1 Fabric Tension (gf) at Different Extensions

Fabric #28432

Stretch Percentage (lengthway)	Tension (gf/cm)	Pressure (gf/cm)	Pressure (mmHg)
5	150	6	4.6
10	275	11	8.4
15	385	15	11.8
20	490	20	15
25	600	24	18.4
30	685	27	21
35	780	31	23.9
40	880	35	27
45	970	39	29.7
50	1065	43	32.6
55	1155	46	35.4
60	1250	50	38.3

Fabric #25034

Stretch Percentage (lengthway)	Tension (gf/cm)	Pressure (gf/cm)	Pressure (mmHg)
5	150	6	4.6
10	265	11	8.1
15	365	15	11.2
20	465	19	14.2
25	560	23	17.2
30	655	26	20.1
35	730	29	22.4
40	800	32	24.5
45	880	35	27
50	950	38	29.1
55	1035	41	31.7
60	1100	44	33.7

Table 3.2 : The Calculation of Interface Pressure on a Cylindrical Surface (assummed the diameter of the curve surface is 0.1 meter) base on the Tension Force of the Elastic Fabric

3.2.2 Experimental Measurement of Interface Pressure for Pressure Garments Using a Cylindrical Tube

The measurement of pressure garment compression exerted on the human body can be made while patients are actually wearing the garments or in the laboratory when the garments are drawn over a model. In this chapter, the effects of garment compression on different curvatures were examined using a simple cylindrical model.

The model is a simple cylindrical tube, with no geometry involved; such as location or shape of underlying bone. The cylindrical tube models are made in nine sizes (range from 12.3cm to 81.7cm in circumference), such size range is similar to the limb sizes of human adults. Efforts were made to study the interface pressure on a cylindrical tube model with a circumference smaller than 12.3cm, but the measured results obtained from the Oxford Monitor MKII show high inconsistency. It is because the size of the sensor is quite large (size of the sensing cell of Oxford Monitor MKII is 2cm x 2cm) relative to the interface surface of tube model, the accuracy of the pressure measurment will surely be affected when the sensor is bent into curve shape and covered a comparatively large area of the interface surface. To measure the pressure on a cylindrical tube model with a circumference larger than 81.7cm is also difficult, because the pressure exerted by pressure garments will be fairly low with such small curvatures (especially when the size of garment is cut only 5-10% smaller than the tube model), even though the manufacturer claim its design is for pressure measuring ranges 0-300mmHg, low accacury appears when the pressure to be measured is below 5mmHg.

All tube models were made of rigid materials and were covered with a thin layer of foam (of thickness 5mm) on the surface. This preparation is necessary to make the surface of the the cylindrical tube model similar to the surface of the limbs of the human body, and it is assumed the tissue surface is homogenous, so that even pressure may be applied on the curved surface if uniform loading could be applied by the pressure garments. Another reason to add a layer of foam on the tube model surface is due to the design of the pressure monitor (Oxford Monitor MKII), the air-pumped plastic sensor of the monitor cannot measure accurately over a rigid surface, because any gap in between the two interface surfaces will affect the consistancy of sensing activity.

The tests were performed on 63 sets of pressure garments (in the form of fabric tubes) which were made based on the sizes of the cylindrical tube models. Two elastic Lycra fabrics (#25034 and #28432) were used for this study. Each of the fabrics were cut in rectangular shape with the long edges parallel to the wales direction of the fabric (i.e. the stretch direction of the fabric) and were made in the form of tubes by seaming at their two vertical edges. All the test samples were seamed by the 3-point zig-zag stitch with 1 cm seam allowance from the cut edges (as shown in Fig. 3.1).

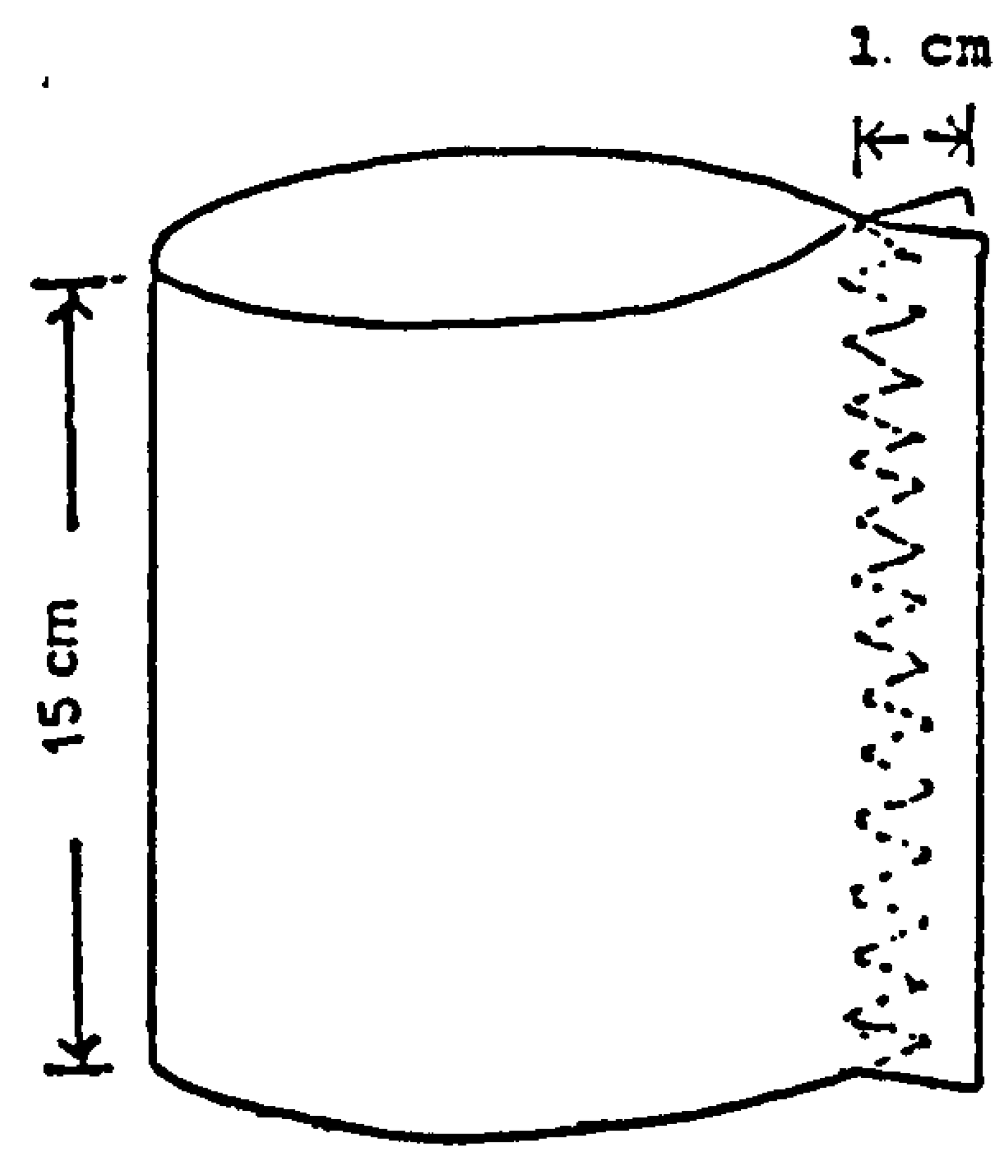


Fig. 3.1 Fabric Tube Sample Seamed by 3-Point Zig-Zag Stitch with 1 cm Seam Allowance

A simple investigation had been carried out before the decision on the type of seam for seaming the fabric tube samples. As the two thread zig-zag lockstitch (B.S.304) is the conventional type of stitch used by the hospitals in H.K. and U.K., based on this type of stitch, specimens are sewn with different stitch width (range from 2mm to 6mm); stitch density (range from 5 s.p.cm. to 14 s.p.cm.) and stitch tension are compared for their suitability for seaming the tested fabrics as well as the accuracy in controlling the measuring of the seamed garments.

It is observed that when the stitch width is narrow (e.g. 2mm) the seam appearance looks best, but the stitch is not good enough to hold the joint edges securely particularly with the net structure fabric #25034, and because the tensile force will be localized at the stitch of narrow width, the seamed area will be damaged more easily when the seam is under stress. When the width of seam becomes bigger (e.g. 5mm-6mm), the bulkiness of seam increases, but the elasticity of the seam becomes better. And because of the seam grinning which occurs when the seam is stressed open, the measurement of the seamed specimen will be increased if the fixing point of the joined seam is shifted from one edge of the zig-zag stitch (the edge 'A') to other edge of the zig-zag stitch (the edge 'B' as shown in Fig. 3.2). The problem of seam grinning is higher when the zig-zag stitch is sewn in bigger width and loose tension, and thus the measurement of the test specimens will be more difficult to be controlled. If the stitch tension is adjusted relatively tighter, seam grinning will be decreased but seam elasticity and seam appearance are also affected. The seam area will form a bulge, if the stitch tension is too high. When the specimen is sewn of high stitch density (e.g. 12 s.p.cm or above), the seam becomes elongated when too much thread is engaged into the seam, and the seam elasitity is decreased as well. When the stitch density is low (e.g. 5-6 s.p.cm), it is easier to adjust the stitch tension and keep the seam flat and straight on the sewn fabrics, but the strength and elasticity of the seam are lower especially when the stitch width is large.

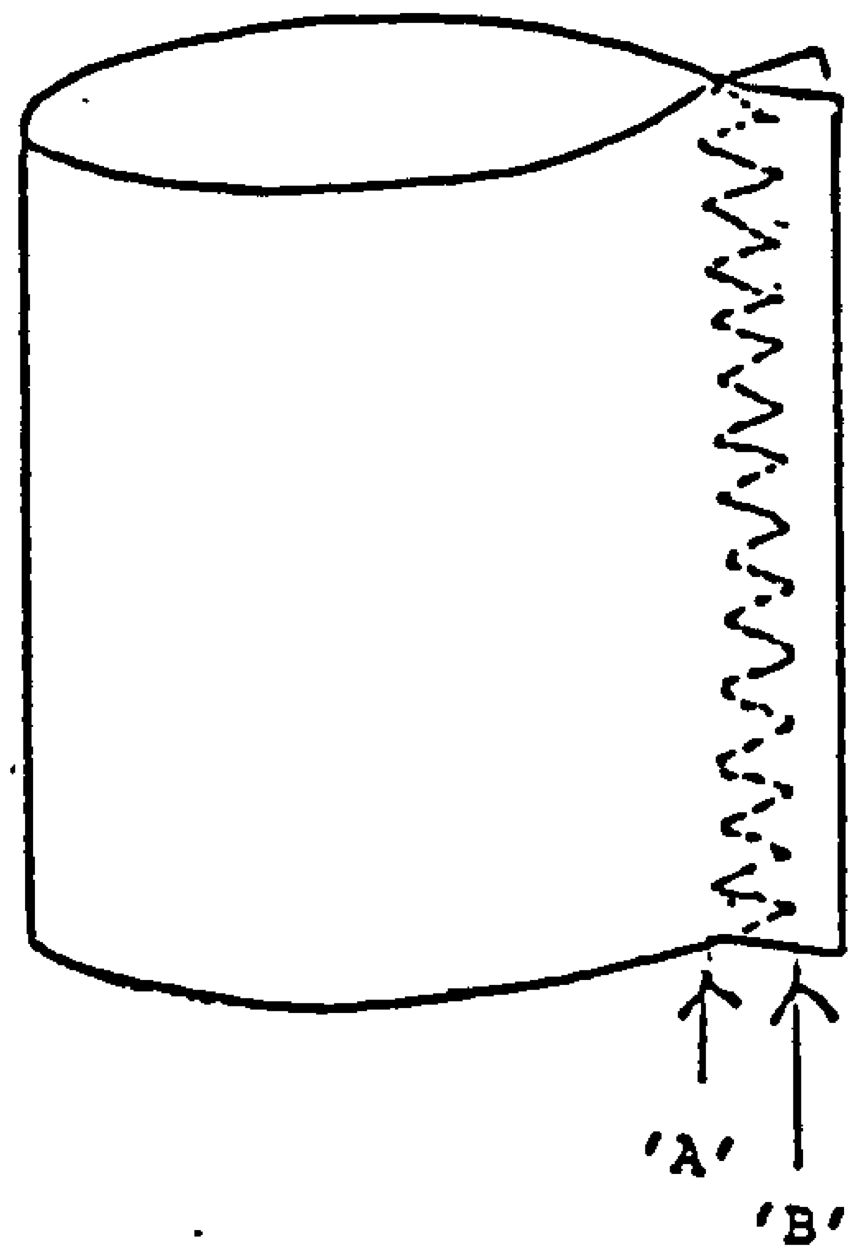


Fig. 3.2 The Join Seam of Zig-Zag Stitch will shift from Edge 'A' to Edge 'B' under strain

After comparing the zig-zag stitch (B.S.304) in various width and densities, it was decided to choose the stitch width 4mm and the density 8 s.p.cm for seaming the specimens. However, the seam grinning problem still affected the accuracy of the measurement of the specimens, therefore another kind of zig-zag stitch (B.S.308) was selected to replace the original B.S.304. The 3-point zig-zag stitch (B.S.308) has an additional interlocking stitch at the centre of each zig-zag, so the amount of seam grinning will be minimized to half when the seam is under stress, and thus the measurement of the specimen can be controlled more accurately for experimental purposes.

As the stretch direction of these elastic fabrics is lengthways, the circumferential width of the specimen is cut in the wales direction. The length of the fabric tubes were fixed at 15cm, and the finished measurement of the fabric tubes is made 5% to 35% (at 5% intervals within the range) smaller than the circumference of each of the cylindrical tube models. That means there were seven sizes of pressure garment for each size of tube model, and 5 samples are made for each size of pressure garment. Therefore there are 63 sets of pressure garments in different sizes, and each set include 5 garment samples for the study.

3.2.2.1 <u>Experimental Method</u> :

The interface pressures between each fabric tube and each cylindrical tube model was recorded at eight locations. With the join seam allowance of the pressure garment faced up, the pressures were recorded at the centre of the join seam area. Pressure was measured again at the same horizontal level; at the point 180 degree opposite to the join seam, and also at the two points which are 90 degree at the left side; and at the right side next to the seam. In order to ensure the readings were all recorded at the same location between each sample garment, a horizontal line was marked at the center (i.e, 7.5 cm above the open hem) of the fabric tube, and the four measuring locations were marked before the sample garment was stretched onto the tube model.

In order to avoid the unnecessary stress on the garment samples that subsequently may affect the experimental results, care should be taken to insert the garment samples into the cylindrical tubes with the minimum disturbance.

It is difficult to maintain uniform fabric stretch when setting the pressure garment onto the tube model. In order to avoid large variation in fabric tension on different parts of the model surface, after putting the garment specimen onto the cylindrical tube, a small round pencil is inserted in between the garment and cylindrical tube, it is moved around the cylindrical tube two to three times in order to make the distribution of the fabric compression more evenly distributed over the cylindrical surface.

As the garment specimen was stretched to a relative larger size before it is fitted onto the cylindrical tube, sufficient time (3-5 minutes) was allowed the garment specimen to relax on the cylindrical tube to allow the pressure to reach a steady state before pressure measurement were taken. Three sets of reading were taken at each measuring location.

The tests were repeated on the same set of pressure garments after 24 hours, pressure measurements were recorded at the same four locations of the fabric tubes but with the seam allowance of the fabric tubes face down.

3.2.2.2 Results and Discussion :

It is observed that the test results (see Appendix 6) measured at different locations on the cylindrical tubes do not show much differences when the garment specimens are of the same size. Only those measured at the point with the seam allowance face down show a higher pressure than the other seven locations. It was therefore decided to average out the data measured at different locations (except the reading measured at the centre of seam and with the seam faced down), and the results are listed in Table 3.3 .

Based on the data of Table 3.3, the change of pressure vs cylindrical tube sizes for different sizes of pressure garment is compared and presented on Graph 3.1.

From the result shown in Table 3.3 and Graph 3.1, it was noted that when the size of garment specimen become smaller (i.e., the reduced percentage of the garment specimen become higher); obviously the pressure induced on the same size of cylindrical tube become higher.

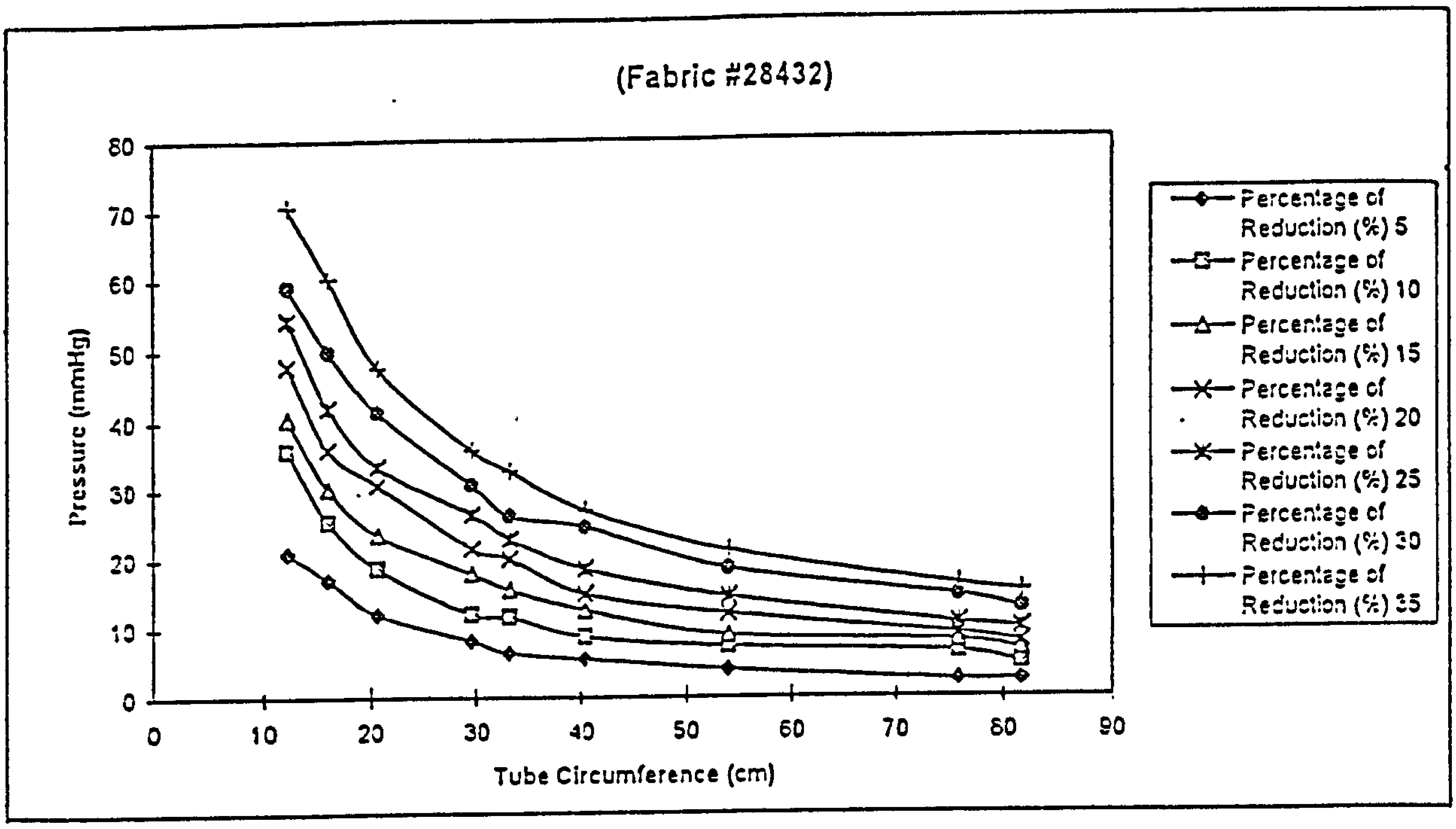
Fabric #28432

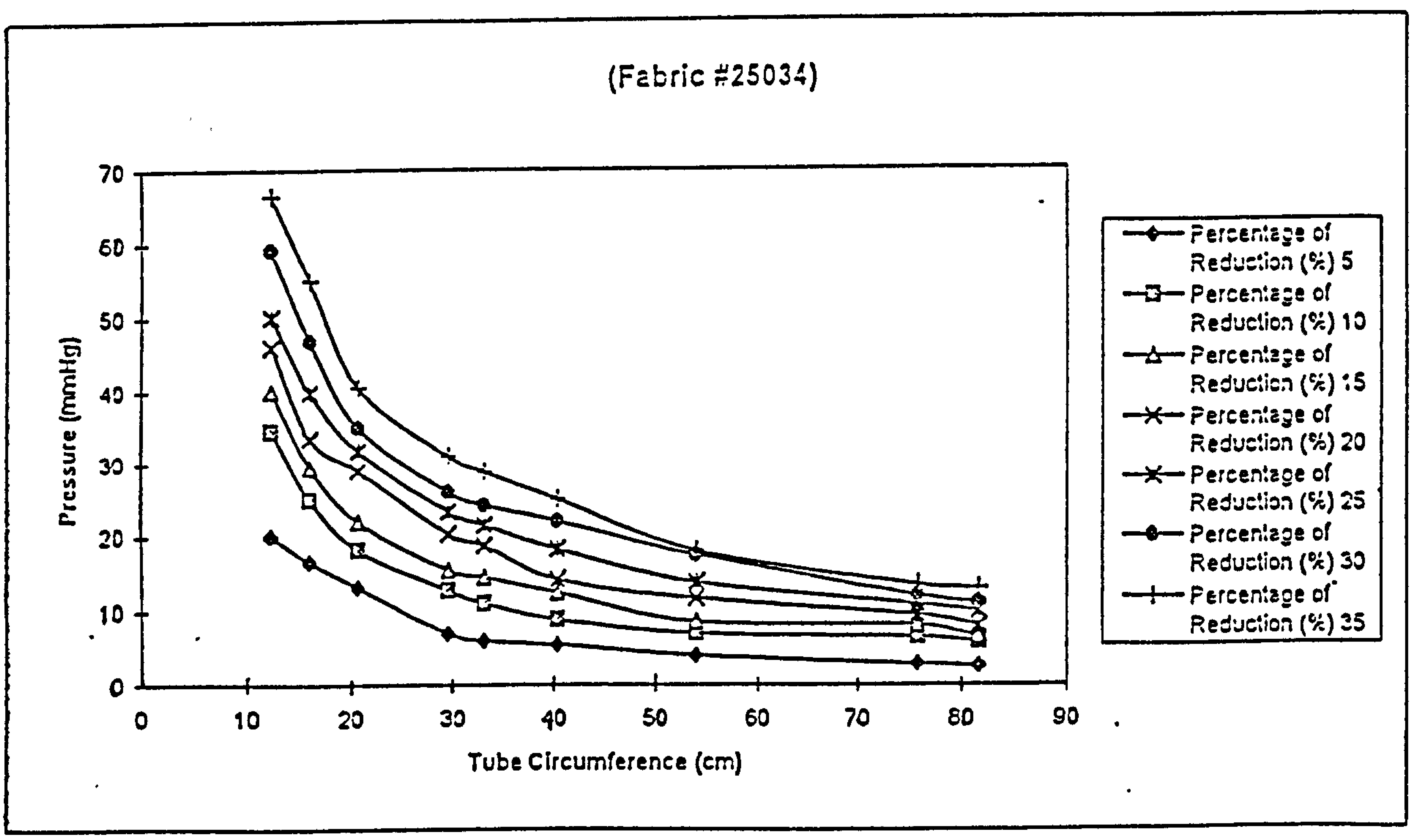
Tube Size (cm)	Percentage of Reduction (%) 5	10	15	20	25	30	35
12.3	20.8	35.8	40.5	48.0	54.5	59.2	70.6
16.0	17.0	25.4	30.2	36.0	42.1	50.0	60.3
20.7	12.0	18.6	23.5	30.8	33.5	41.4	47.7
29.6	8.2	12.0	17.9	21.5	26.4	30.8	35.8
33.2	6.4	11.6	15.5	20.0	22.8	26.2	32.8
40.4	5.6	8.8	12.6	14.9	18.5	24.5	27.0
54.0	4.0	7.4	9.0	12.0	14.5	18.5	21.1
76.0	2.5	6.6	8.1	9.2	10.7	14.6	16.2
81.7	2.5	5.0	7.0	8.0	10.0	12.8	15.2

Fabric #25034

Tube Size (cm)	Percentage of Reduction (%) 5	10	15	20	25	30	35
12.3	20.0	34.5	40.0	46.0	50.1	59.2	66.4
16.0	16.6	25.0	29.4	33.4	39.8	46.8	55.0
20.7	13.2	18.2	22.0	29.0	31.8	35.0	40.5
29.6	7.0	12.8	15.5	20.3	23.3	26.0	31.0
33.2	6.0	11.0	14.5	18.8	21.5	24.2	28.9
40.4	5.4	8.8	12.4	14.1	18.2	22.0	25.0
54.0	4.0	7.0	8.5	11.6	13.7	17.4	18.0
76.0	2.8	6.5	8.0	9.5	10.8	12.0	13.5
81.7	2.5	5.8	6.5	8.0	10.0	11.0	13.0

Table 3.3 : **Table of Pressure (mmHg) Measured at Different Reduced Percentage Of Fabric Tube Measurement VS Different Sizes Of Cylindrical Tube Models**





Graph 3.1 A Comparision of the Pressure Change (mmHg) Vs Different Sizes of Tube (Circumference range between 12 cm to 80cm) between Pressure Garments at Different Percentage of Reduction

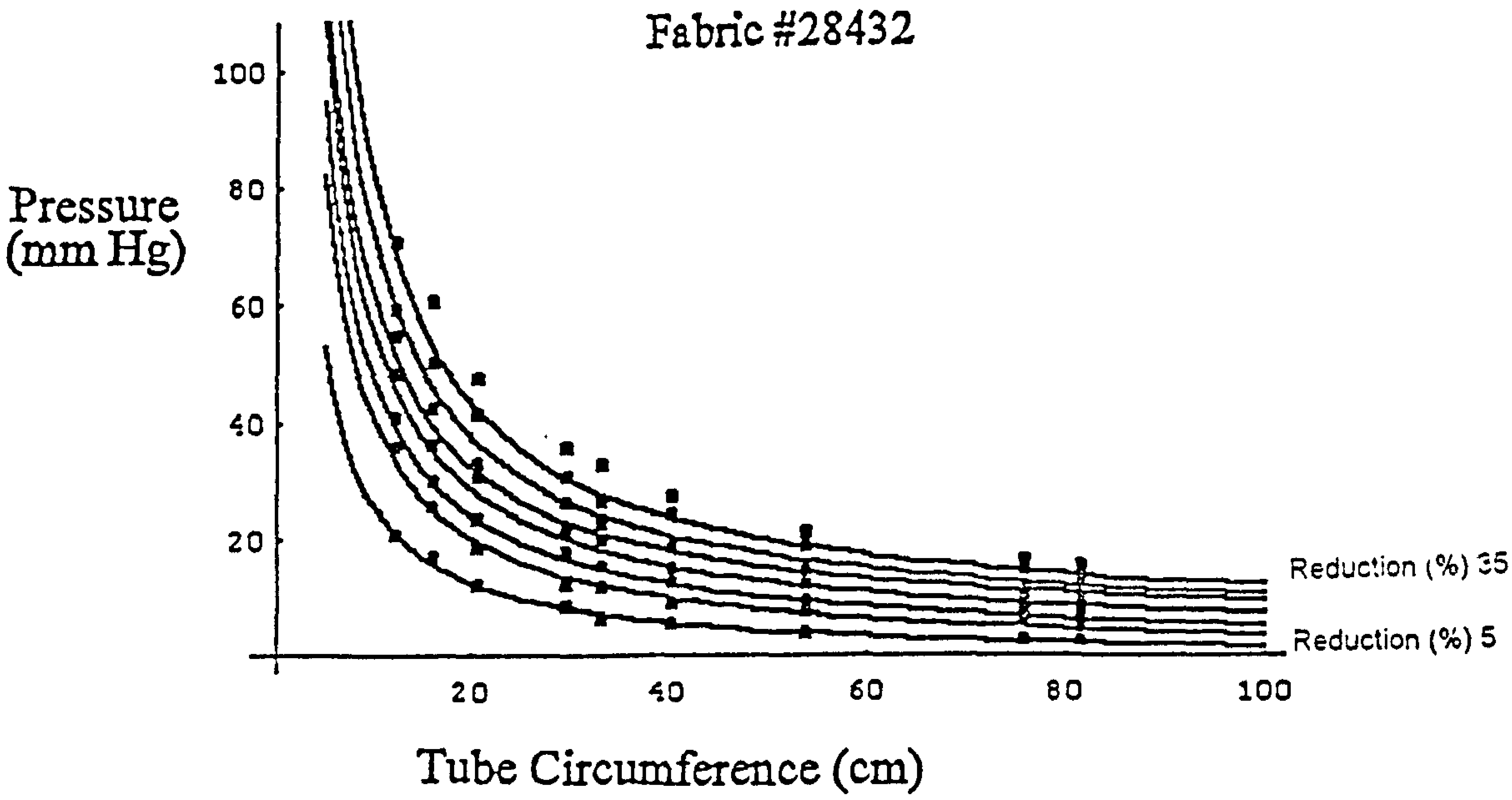
Based on the compression created by the elastic garment specimen of the same size, it was noted that the pressure induced on the cylindrical tube was reduced when the size of the cylindrical tube is increased. This result correlated to the theory of the Laplace Law (Pressure = Tension/Radius).

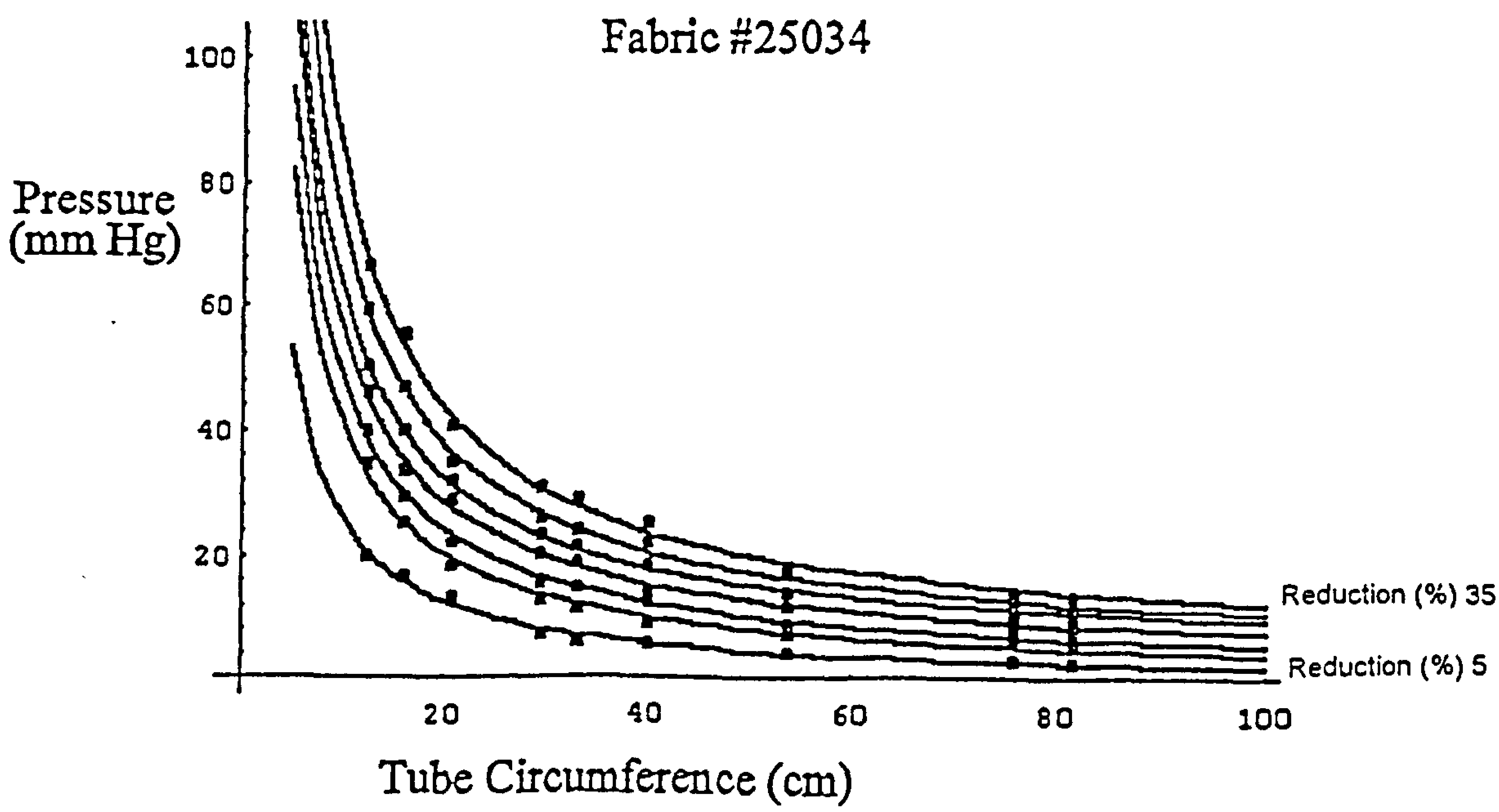
It was also found that when the reduced percentage of garment specimen was increased from 5% to 35%, and if the size of the cylindrical tube model was fixed at the same circumference; the range of pressure change became smaller when the size of the cylindrical tube model became bigger. For example, when the circumference of the cylindrical tube model was 16cm and the reduced percentage of the garment specimen was 5%, the interface pressure was 16.6mmHg for the fabric #25034, the interface pressure increases to 55mmHg when the reduced percentage of the garment specimen was 35%, the range of pressure change is 38.4mmHg. However, when the cylindrical tube size was 81.7cm in circumference, the range of pressure change was only 10.5mmHg when the reduced percentage of the garment specimen was changed from 5% to 35%.

The study in 3.2.2.1 was exploratory in nature, as explained before, the size of the cylindrical tubes are limited within the range from about 12cm to 82cm. However, the techniques of curve fitting and data interpolation could be applied with the aid of a computer program. This enables us to estimate the possible interface pressure beyond the experimental range of cylindrical tube sizes (See Graph 3.2).

From the Graph 3.2, it is observed that the experimental data recorded in lower reduced percentage (for example 5% reduction) shows greater variation to the fitted curve , but when the reduced percentage of the garment specimen was 10% or higher, the experimental data lies better on a curve line. This explains that greater variations in interface pressure occured when the pressure garments were stretched by low extensions, this may be because of the interface pressure was affected by the weight of the fabric, and/or due to the pressure monitor could not function very accurately when the interface pressure is very low.

It was also noted that the interface pressure was below 10mmHg when the size of cylindrical tube was above 100cm circumference. The interface pressure induced by different sizes of pressure garments became similar when the size of tube becomes very large. Our simple model predicts that the interface pressure approaches zero as the size of the cylindrical models tends to infinity.



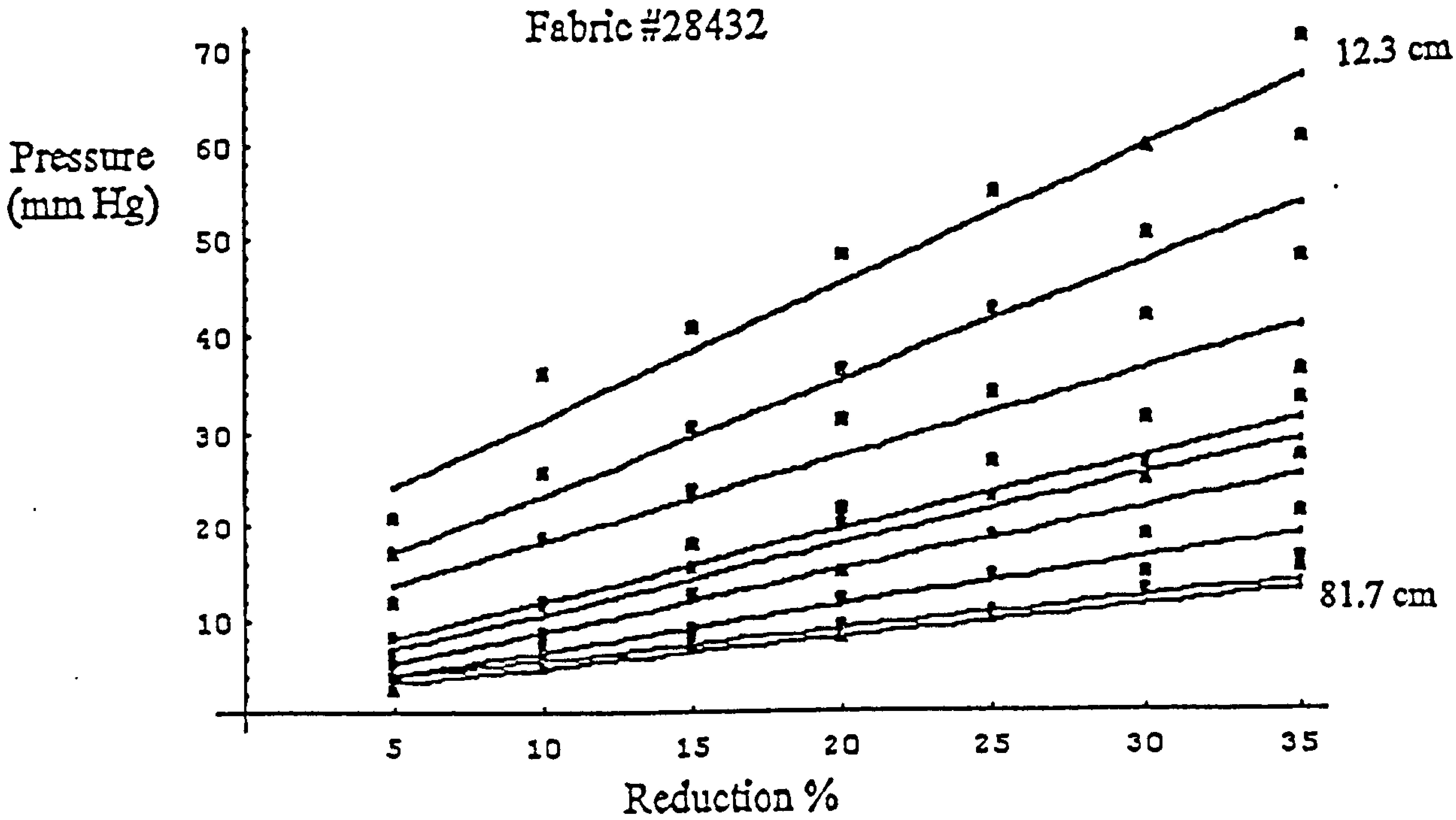


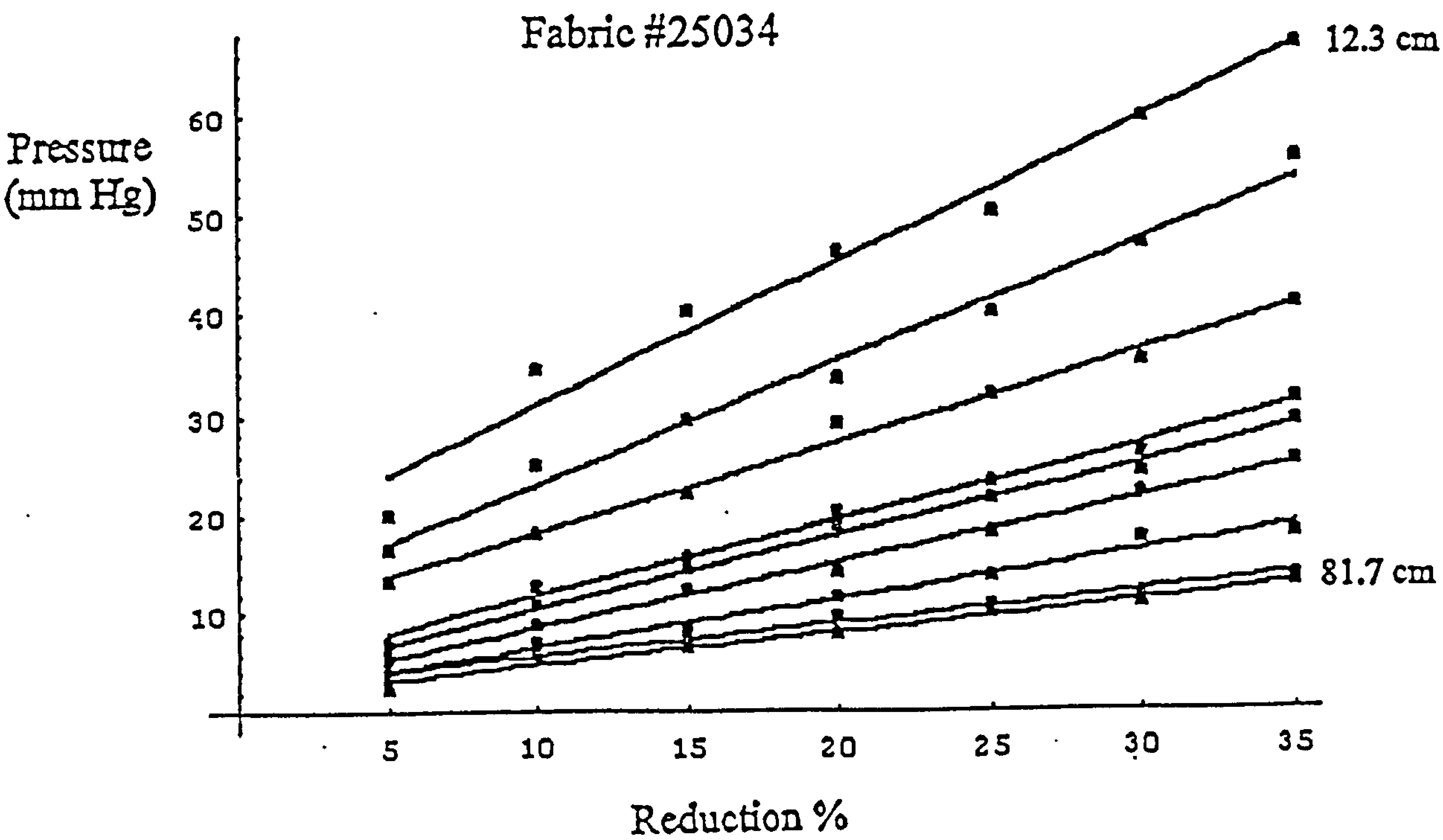
Graph 3.2 A Comparison of the Pressure Change (mmHg) Vs Different Sizes of Tube (Circumference range beyond 12cm to 80cm) between Pressure Garments at Different Percentage of Reduction

On the other hand, when the cylindrical tube size is below 10cm in circumference, a small change in the reduced percentage of the size of the pressure garment will affect much on the interface pressure. For example, when the size of the cylindrical tube model is decreased to 5cm in circumference, the possible change of interface pressure estimate from the Graph 3.2 is around 15 -20mmHg if the size of the pressure garment is changed 5%.

Our model predicts that the interface pressure tends to infinity as the size of the cylindrical model approaches zero. However, the size of the cylindrical tube model approaches a finite non-zero value and cannot be reduced indefinitely.

The graph plotted with the interface pressure vs the reduced percentage of garment specimen is basically linear (as shown in Graph 3.3), this indicated that the interface pressure measured from each size of the cylindrical tube model is basically directly proportional to the reduced percentage of the pressure garments. However, the straight lines of the graph are not through the origin, this indicates that some sort of pressure exists even when there is no extension on the pressure garment, and this kind of contact pressure was higher when the circumference of the tube is smaller.



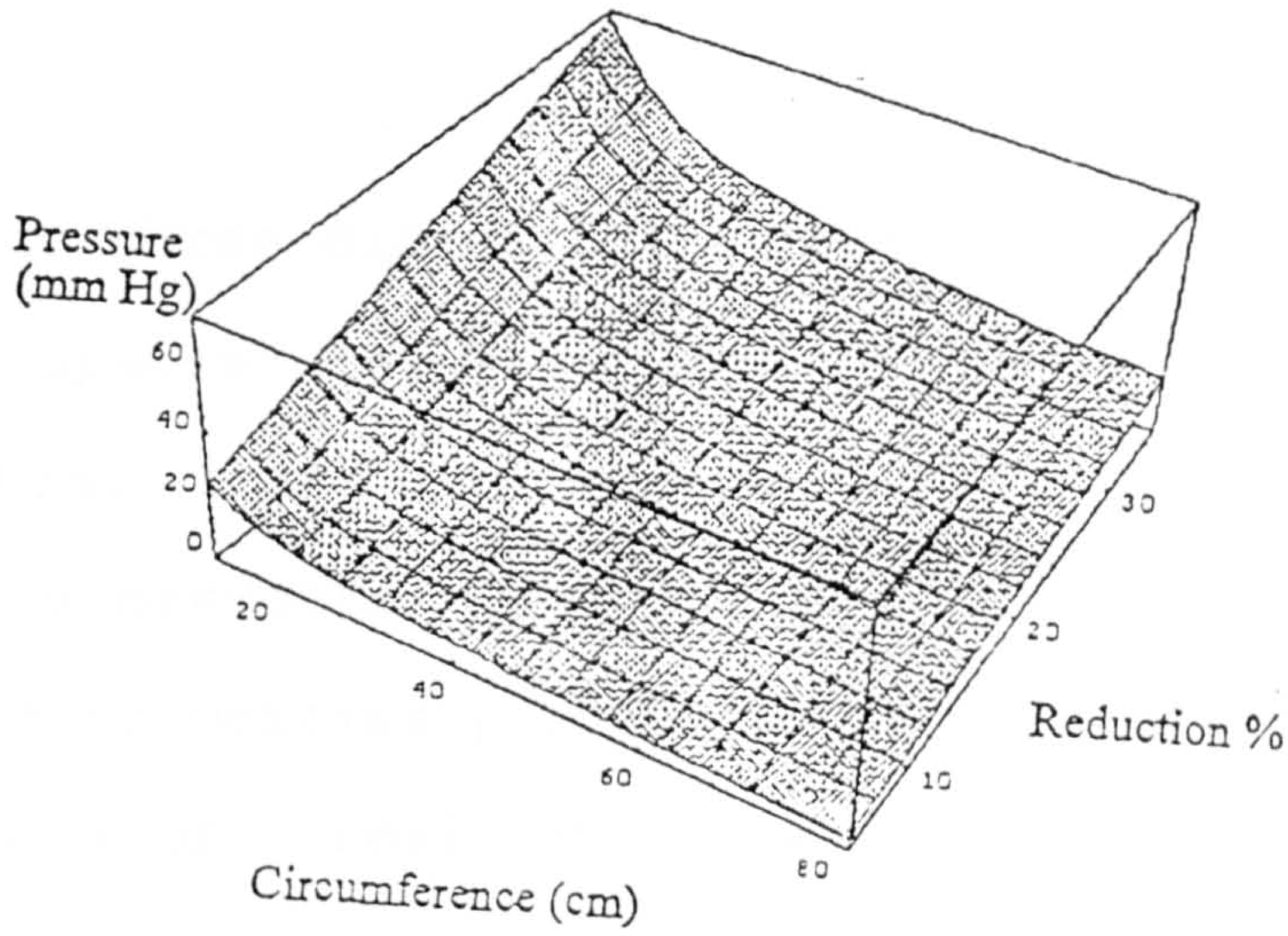


Graph 3.3 A Comparison of the Pressure Change (mmHg) Vs Change of Sizes of Pressure Garment (Reduction %) between Different Sizes of Tube Model

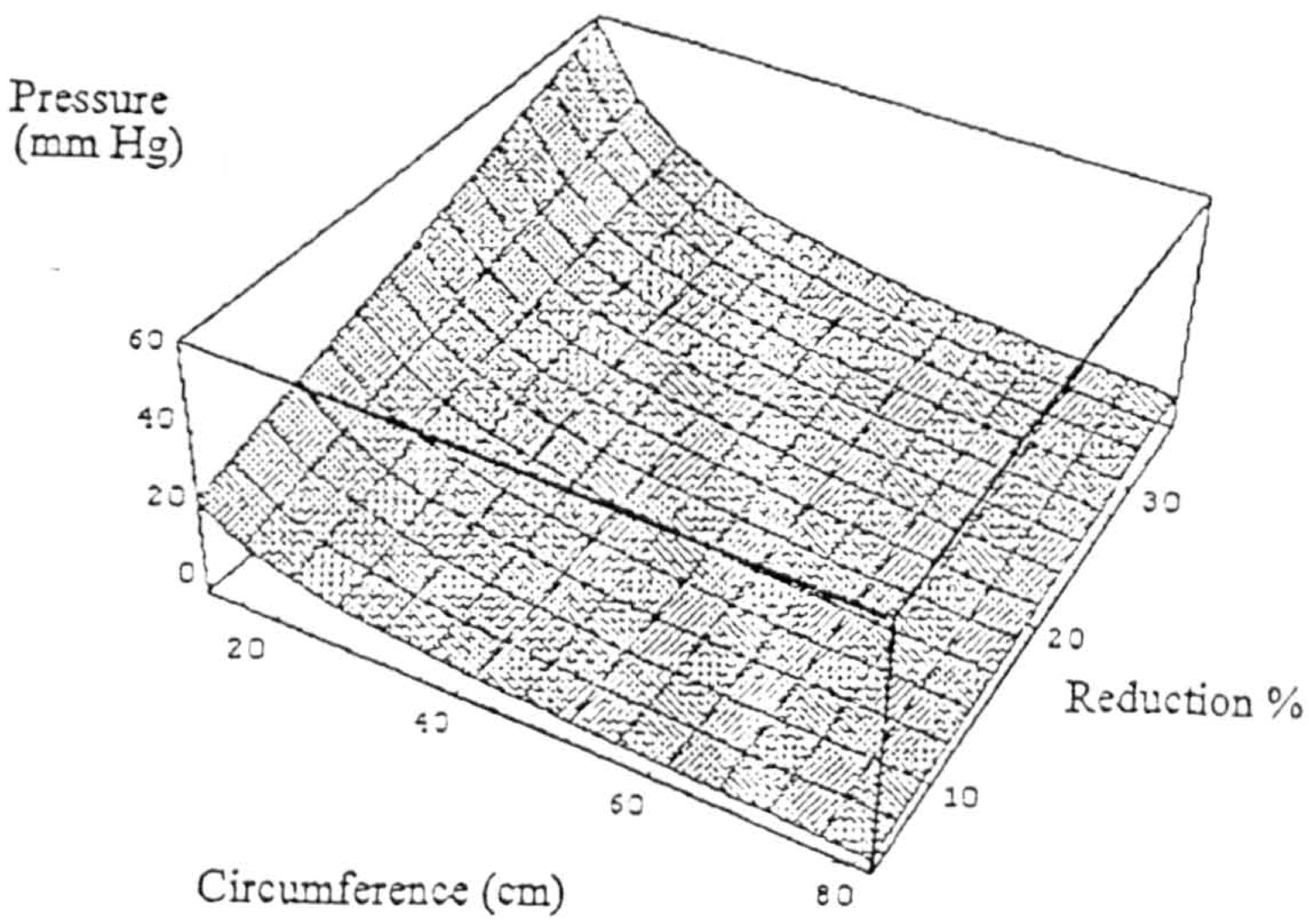
The relationship of the three variables: interface pressure, reduced percentage of garment, and the curvature of the interface surface, was worked out by combining the two sets of graphs (Graph 3.2 and Graph 3.3). A three dimensional curve surface (as shown in Graph 3.4) indicates the pattern of pressure change vs the change of cylindrical tube size and vs the change of the reduced percentage of the garment. The two fabrics tested show similar patterns.

Further information can be derived from the Graph 3.4. For example, the possible interface pressure could be worked out if the size of the cylindrical tube and the size of the garment is given, or it is also possible to find out the correct size of garment for a particular size of cylindrical tube if a particular range of interface pressure is specified.

Fabric #28432



Fabric #25034



Graph 3.4 A 3-Dimensional Surface Indicating the Relationship of the Interface Pressure, Reduced Percentage of Pressure Garment and the Surface Curvature

3.2.3 Measurement of the Interface Pressure for Garments Measured on Human Body

Skin is a three-dimensional network of connective tissue fibres. Spaces between these fibers are filled with interstitial fluid and ground substance. The compression induced by pressure garments on the human body depends on the tissue properties , so that the pressures exerted on the soft tissues of a real leg may differ from those measured on the rigid model. For this reason, it is important to compare the values of compression obtained from a range of pressure garments applied on the limbs of the human body and the measurements recorded from the cylindrical tube model.

Since the limbs of humans have a very variable geometry, the pressure exerted by a particular pressure garments depends on precisely where the measurement is made around the circumference of the limbs. The need to use standard positions for the measurements is therefore particularly important.

In order to study the effect of soft-tissue moulding and tissue displacement by the pressure garments, measurement of skin-and-garment interface pressure is made on the human body. The measurement of the pressure exerted on the limbs by a pressure garment against the measurements recorded from the cylindrical tube model can also be compared.

Subjects and Methods:

A male adult participated in the study. The upper and lower limbs were chosen for measurement and tubular garments were made according to the circumference measured around the limbs. The bony part of the limbs (such as the joints) were deliberately not chosen for pressure monitoring because of the increased curvature and the problem of bending the sensor causing reading errors.

All the measurements were recorded with the subject standing with the legs straight and hands hung down in a natural position. To ensure a correct positioning of the garment tubes which may slip up and down during the wearing process, certain fixed portions of the limbs were used for measuring the pressure with reference to the prominent bony prominence of the body. The acromium process of the shoulder is the most easily palpable part of the area and the circumference of the arm was measured in 10 cm sections below the acromium process. Accurate measurements at every 4 cm regular intervals over the limbs were taken and transferred to drafting patterns for the production of pressure garments, the size of pressure garments produced were made 5%, 10%, 15%, 20%, 25%, 30%, and 35% smaller than the actual size of the limbs.

Separate garment tubes were made for the forearm, thigh and the leg by similar methods. The bony prominence used as a landmark for taking measurements: measurements for the forearm were taken 3cm above the tip of the radial styloid process over the wrist, for the thigh 5cm above the upper pole of the patella bone, and for the leg 5cm below the tibial tuberosity.

The measurements recorded from the limbs of the human subject are listed as below:-

Leg : 27cm; 32cm; 35.7cm; 38.5cm and 39cm

Thigh : 48.5cm; 51.4cm; 54cm; 57cm and 59cm

Hand : 18.7cm; 20.6cm; 23.8cm and 26.2cm

Forearm : 27.2cm; 29cm; 30.6cm and 32cm

The positions of the garments with respect to the limbs were defined by marking both the limbs and the garments at regular intervals (i.e. every 4 cm - the same way to take the limbs measurements). At each circumferential position, four points at regular spacing were marked And to ensure the same area is used for measuring interfaced pressure, four points at regular intervals were marked at each circumferential line , and one of the four points was placed at the joint seam of the garments.

The skin-and-garment interface pressure at each of the measuring point marked on the garment sample were taken by the Oxford Pressure Monitor MKII. After the subject put on the garments, he deliberately moved the limbs for two to three minutes to make the garments freely relax on the limbs surface. The markings on the limbs and garments were checked to ensure they coincided before recording the pressure measurements.

The tests above were repeated using three sets of samples for each sizes of pressure garments. The result of the experiment was shown in Appendix 7.

As the pressure recorded from the "leg" and the "forearm" showed some difference even when their circumference were the same; for example, when the reduced percentage of pressure garment made of farbic #28432 was 20%, the interface pressure recorded from the leg was 17.3mmHg at the circumference 32cm, but it was only 14.4mmHg at the forearm of the same size; it was therefore decided to consider the measurements into two groups: the lower limbs (range from 27cm to 59cm); and the upper limbs (range from 18.7cm to 32cm).

The interface pressure was not recorded for the upper limbs when the reduced percentage of pressure garments was up to 35% , it was because there was no zip or velcro opening on the garment samples, thus it was quite impossible to put the garments on human without over-stretching the samples. In the case of lower limbs, when the pressure garments were cut only 5% smaller than the limbs, the interface pressure recorded showed very high inconsistency because of the very low pressure on large circumference. It was therefore decided to excluded those two sets of data in order to avoid affecting the accuracy of results.

3.3 ASPECT RATIO :

The aspect ratio of a specimen is normally defined as the width of the specimen divided by the guage length. The choice of specimen size and aspect ratio must be taken account because the load-strain relationships measured may vary with specimen width and gauge length.

According to the Laplace Law, it is evident that, if a fixed force is used, the pressure induced in a body will depend on the area of the latter, pressure decreasing as area increases. Equally obviously, pressure will increase with increasing force if the area remains constant.

When a pressure garment is applied to different sizes of limb, if the garment is cut the same percentage smaller than the actual size of the limbs, higher pressure is found on the garment applied to smaller size of limbs, and pressure decreasing as the size of the limbs increases. The results correlate with the principle of the Laplace Law.

It may be argued that change of the pressure on difference radius of interface surface may be caused by the change of fabric tension. If the size of the limbs is changed, that means the size of the pressure garment is also changed with different aspect ratio in width and length, such changes in aspect ratio of the elastic fabric may affect the fabric tension even though the material undergoes the same amount of stretch.

3.3.1 Method of Test :

In order to assess the influence of aspect ratio to the tensile properties of elastic fabrics used for the manufacturing of pressure garments, two tests were carried out as below:

3.3.1.1 Cut-Strip Test

Cut-strip tests were designed to compare the tension force produced by the elastic fabrics (#28432 and #25034) cut in different gauge length. An Instron Tensile machine with flat clamp in width 5cm was used for the test. All fabric specimens were in width 5cm and in gauge length the same as the circumference of the cylindrical tube model (i.e., 12.3cm, 16cm, 20.7cm, 29.6cm, 33.2cm, 40.4cm, and 54cm), each specimen had 5cm allowance at each end for mounting on the flat clamps. The long edges of specimen were the stretch direction of the fabric. The tension load cell scale was 5kg, and all the specimens were mounted to the clamps manually under zero load and extended at constant rate of 200mm/min.

All the specimens were extended by 5.3%, 11.1%, 17.6%, 25%, 33%, 42.9% and 53.8% in lengthway direction, such range of extension equals to the amount of fabric stretch when the specimen is cut 5%, 10%, 15%, 20%, 25%, 30%, 35% smaller than the actual size of the cylindrical tube model. (The relationship between the elongation percentage of elastic fabric and the reduced percentage of pressure garment was presented at Table 3.7 and Graph 3.15).

Based on a fixed extension, the tension force of the specimen was recorded. As the load under stress at each given extension was very unsteady (stress decay rapid) during the first minute, it was decided to record the tension force after the specimen was extended for one minute at a fixed stretch percentage. The test results are presented in Table 3.4 and Graph 3.5.

Fabric #28432

Stretch Percentage

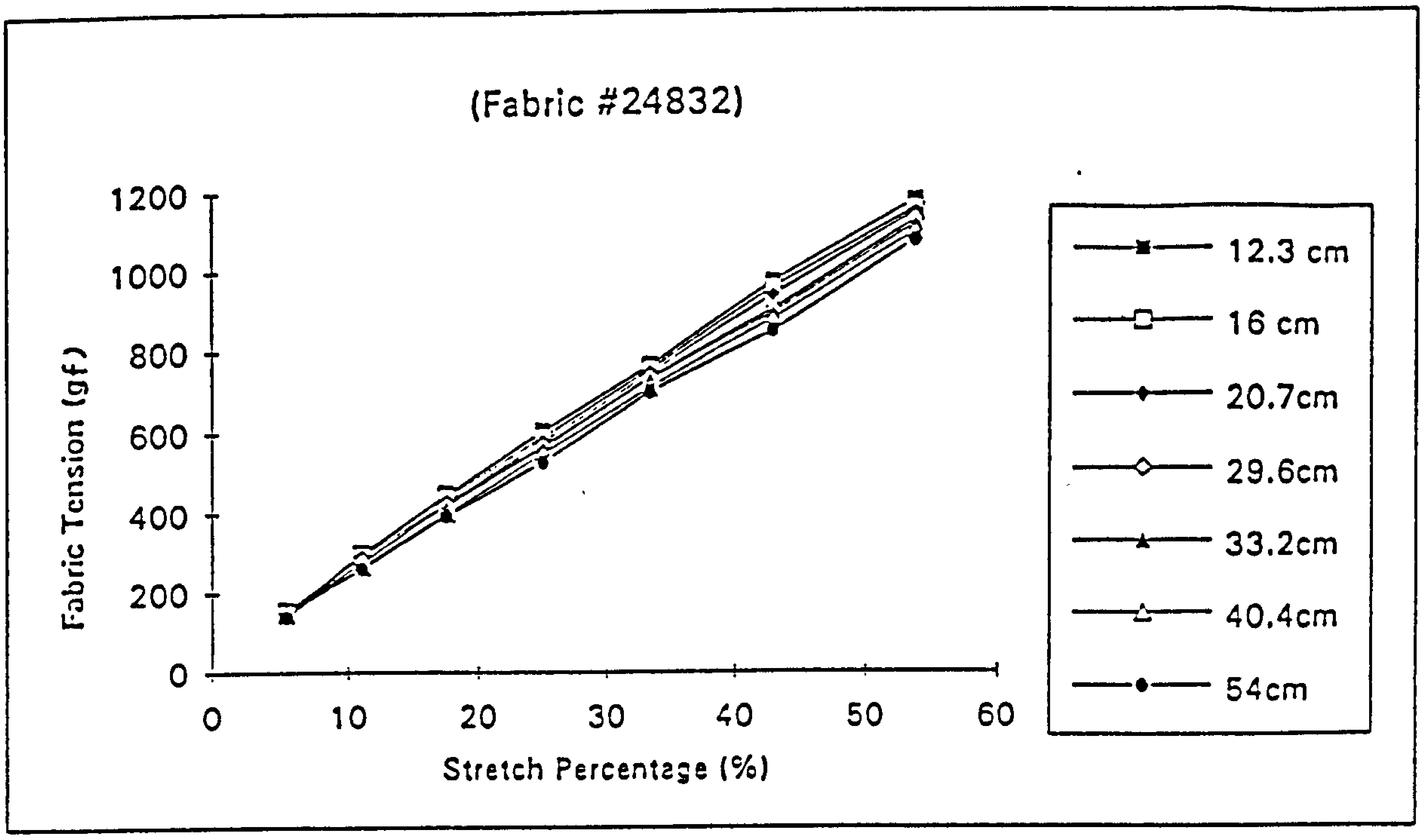
Guage Length	Aspect Ratio	5.3	11.1	17.6	25.0	33.3	42.9	53.8
12.3	0.41	155	300	450	605	765	975	1180
16.0	0.31	150	295	445	590	755	960	1160
20.7	0.24	150	290	430	580	745	940	1150
29.6	0.17	150	280	425	570	735	905	1130
33.2	0.15	145	275	420	565	730	895	1120
40.4	0.12	145	265	400	550	710	880	1100
54.0	0.09	140	260	395	530	700	850	1080
Coefficient of Variation		3.3149	4.9862	4.5375	4.0606	2.9441	4.5626	3.0799

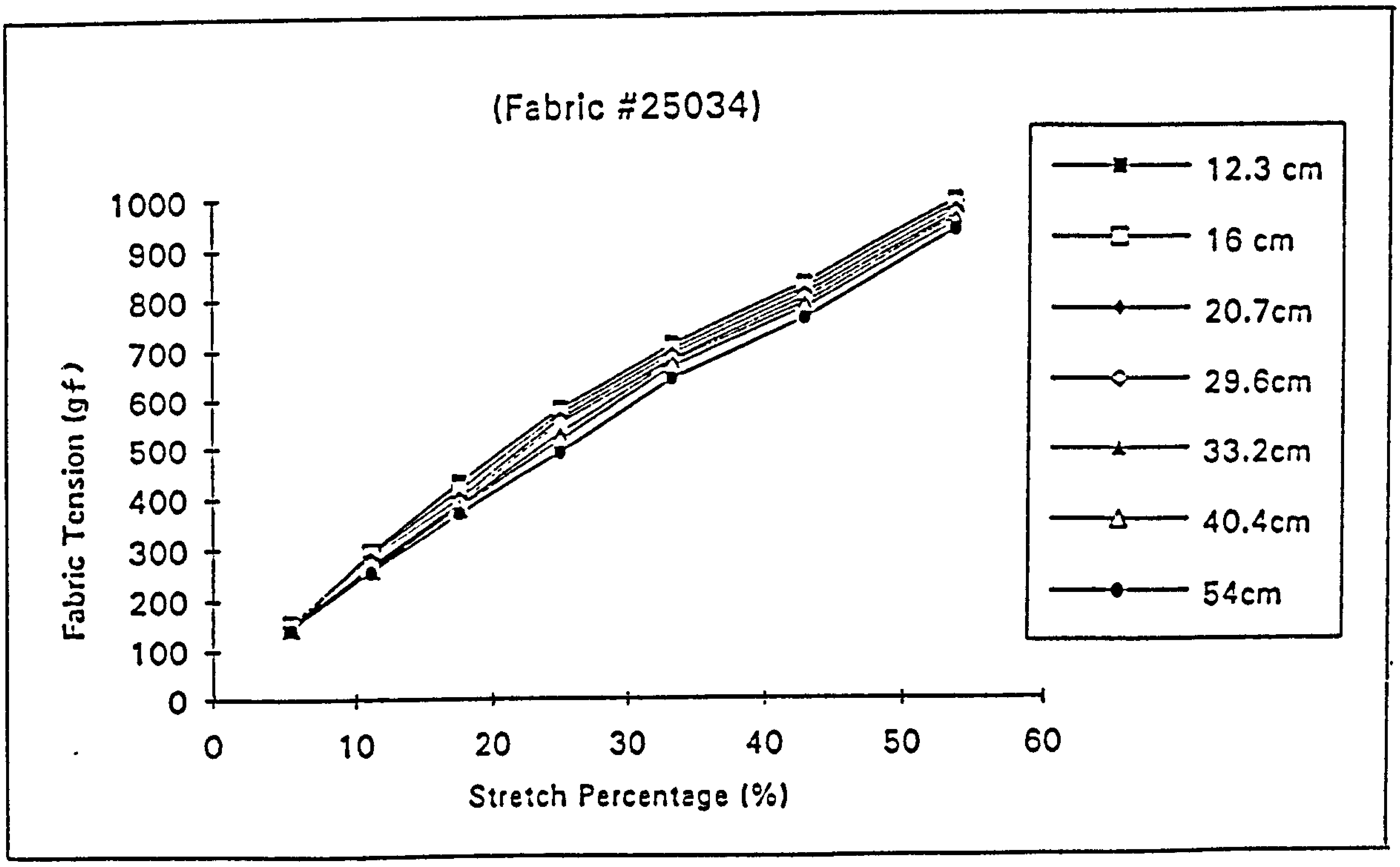
Fabric #25034

Stretch Percentage

Guage Length	Aspect Ratio	5.3	11.1	17.6	25.0	33.3	42.9	53.8
12.3	0.41	155	295	430	560	710	830	995
16.0	0.31	150	290	415	550	700	820	985
20.7	0.24	150	285	400	540	690	810	975
29.6	0.17	150	270	390	530	680	800	965
33.2	0.15	145	265	385	530	675	790	960
40.4	0.12	145	260	380	515	665	780	950
54.0	0.09	140	255	370	490	640	760	935
Coefficent of Variation		3.0553	5.2859	4.8903	5.4863	3.1687	2.7944	2.1272

Table 3.4 Tension Force (g force) of Elastic Fabric Measured at Different Guage Length (Aspect Ratio) by Cut-Strip Test





Graph 3.5 The Change of Fabric Tension (gf /cm) Vs Stretch Percentage of Specimen of Different Guage Length (by Cut-Strip Test)

3.3.1.2 Fabric Loop Test

In making tensile tests on fabric strips as described in 3.3.1.1, as the width of the tested specimens were fixed by the flat clamps , it is common for specimens to become narrower over the middle sections than at the grips. The 'waisting' of the specimen results in the yarns at the edges of the tested specimen being stretched more than the yarns at the centre and thus being under greater tension. In order to minimize the influence of the "waisting effect" on the tested specimens, and to examine the effect of change of specimen width to fabric tension, another load-extension fabric test was designed. A set of pins was used to replace the normal flat clamp on the Instron Tensile machine for holding a loop specimen. The pins were in width 16cm and were specially designed to rotate freely on the clamps, this is to minimize the friction on the specimen when it contracts in width under strain.

Specimens were cut in size 15cm (width) x 32cm (length), the free ends of specimens were seamed across at a distance 1cm from the ends to form a fabric loop, the tensile strength of such fabric loop can be found by mounting the fabric loop to the top and bottom pin clamp of the tensile machine (as shown in Figure 3.3). The specimen was extended at a constant rate of 100 of mm/min, chart to cross head ratio 1:1, and the load cell for the test was 5Kg.

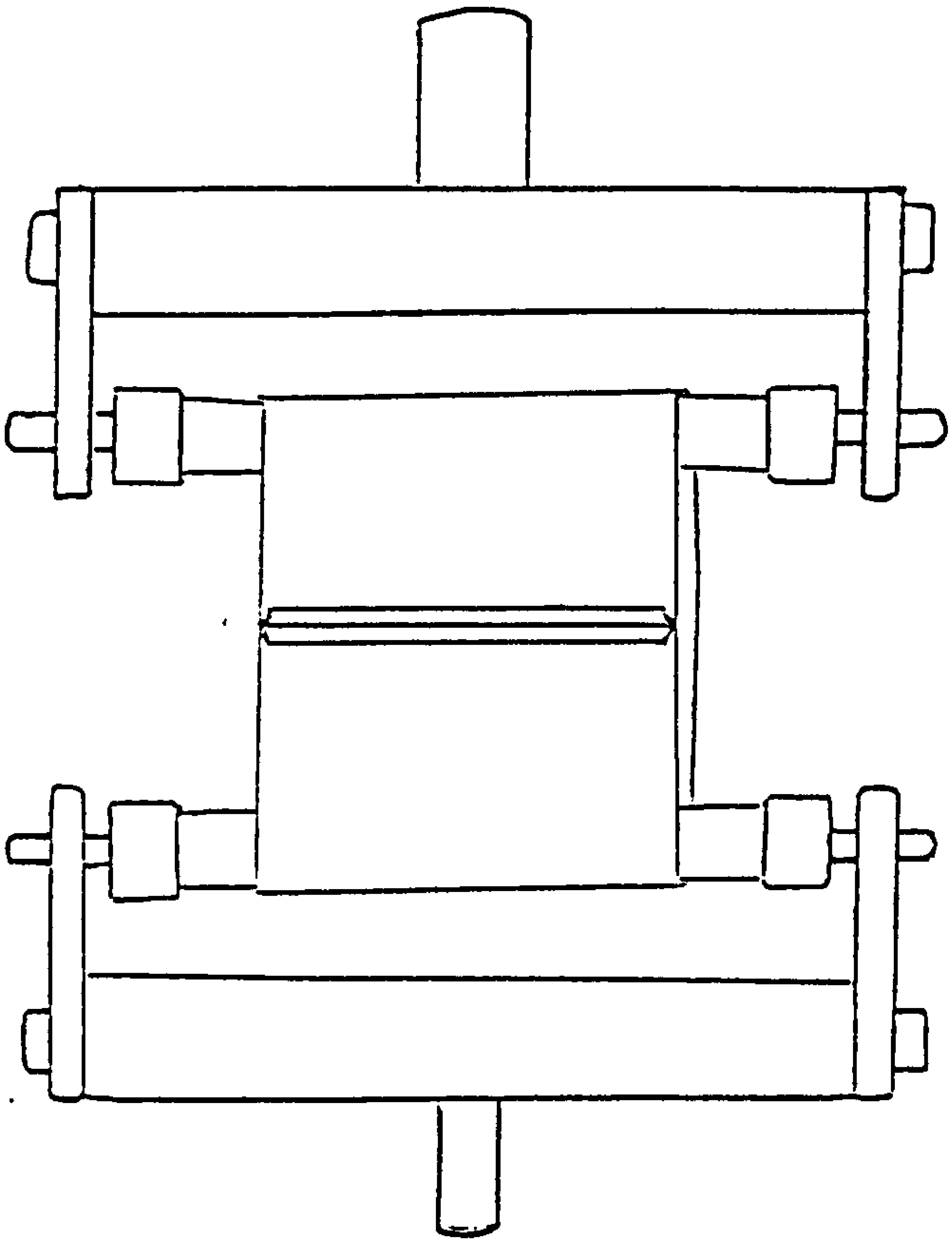


Figure 3.3 Fabric Loop Mounting on the Pin Clamp of Tensile Machine

The pin of the clamp was cylindrical in shape with a diameter of 1.2cm, and the gauge length of the specimen equals half the circumference of the fabric loop between the top and bottom pins. It was decided to measure the tension of the extended specimen at extensions of 20%, 30%, 50%, and 100% from the load-extension curve. A small preload was applied to the specimen to remove internal slack and the origin point on the force-elongation curve was set from this point.

In the case of the "waisting effect" appearing on the specimens during the test, the waisting of the stretched fabric loop was eliminated by hand or by rotating the pin of the clamp manually.

The tests were repeated on other specimen in same length but gauge width was changed to 12.5cm, 10cm, 7.5cm, 5cm, and 2.5cm respectively, two other specimen were made in same gauge width (15cm) but the finished size in length 20 cm and 15cm. The aspect ratio of the specimen to be tested was listed as below:

Specimen Width	Specimen Length	Aspect Ratio
15 cm	15 cm	1
15 cm	20 cm	0.75
15 cm	30 cm	0.5
12.5 cm	30 cm	0.42
10 cm	30 cm	0.33
7.5 cm	30 cm	0.25
5 cm	30 cm	0.16
2.5 cm	30 cm	0.08

The results of the tests was shown in Table 3.5, Table 3.6 and Graph 3.6.

Fabric #28432

Aspect Ratio	Stretch Percentage (%) 20	30	50	100
1.00	19.0	28.6	46.0	130.0
0.75	20.0	27.5	45.6	128.0
0.50	18.8	26.8	44.0	122.4
0.42	19.0	26.7	44.0	121.5
0.33	19.6	28.0	44.7	122.0
0.25	20.0	28.6	45.3	126.7
0.16	19.8	28.4	46.0	122.5
0.08	19.2	28.0	46.0	124.0

Fabric #25034

Aspect Ratio	Stretch Percentage (%) 20	30	50	100
1.00	23.1	32.0	45.3	89.3
0.75	23.5	32.3	45.6	88.0
0.50	23.5	30.9	43.1	85.6
0.42	23.2	31.0	44.0	85.8
0.33	23.8	31.3	43.8	86.5
0.25	23.1	31.5	43.5	85.0
0.16	23.0	31.2	44.0	85.3
0.08	23.2	31.2	43.2	85.2

Table 3.5 : The Tension Force (gf/cm) of Elastic Fabric Measured at Different Aspect Ratio by Fabric Loop Test

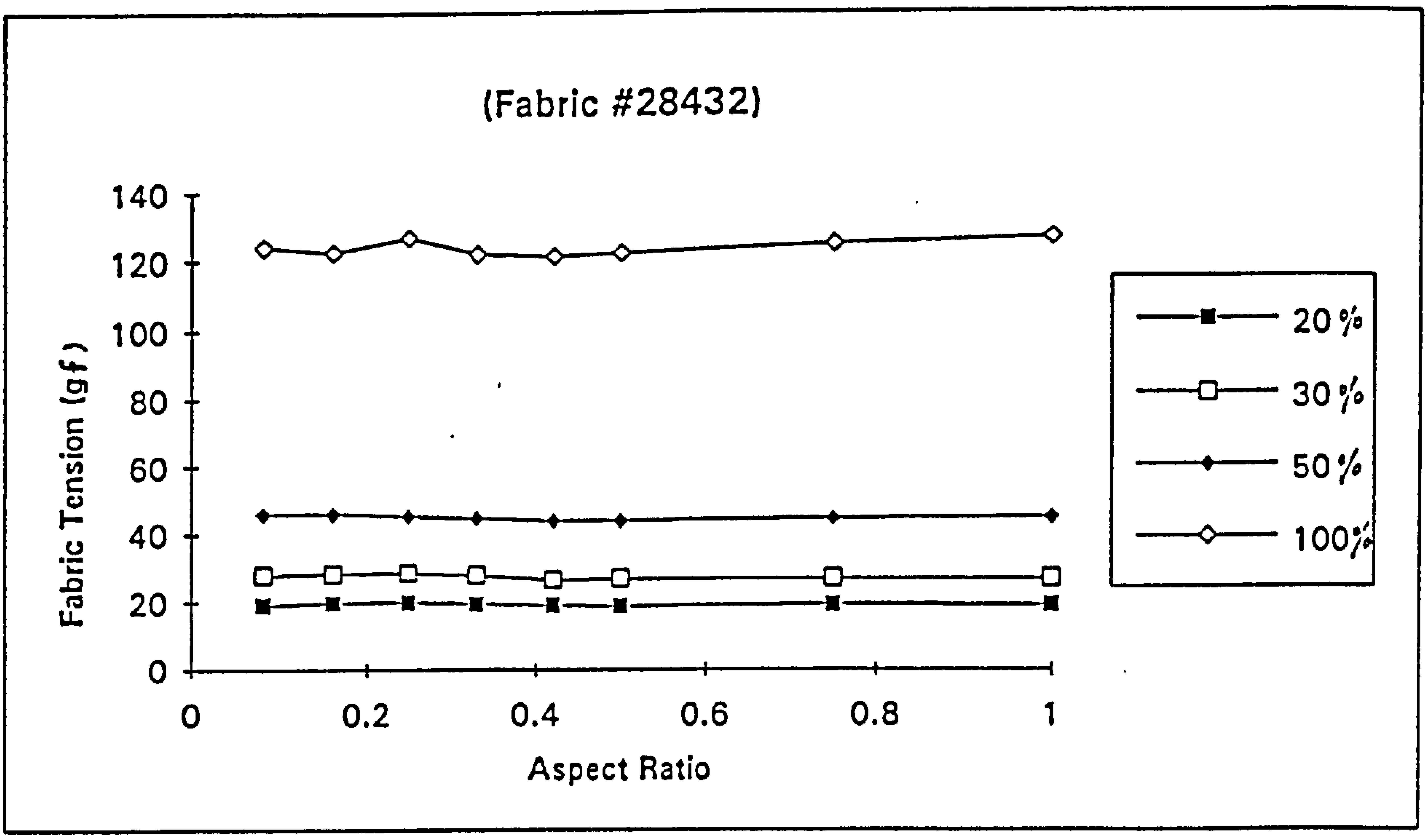
Fabric #28432

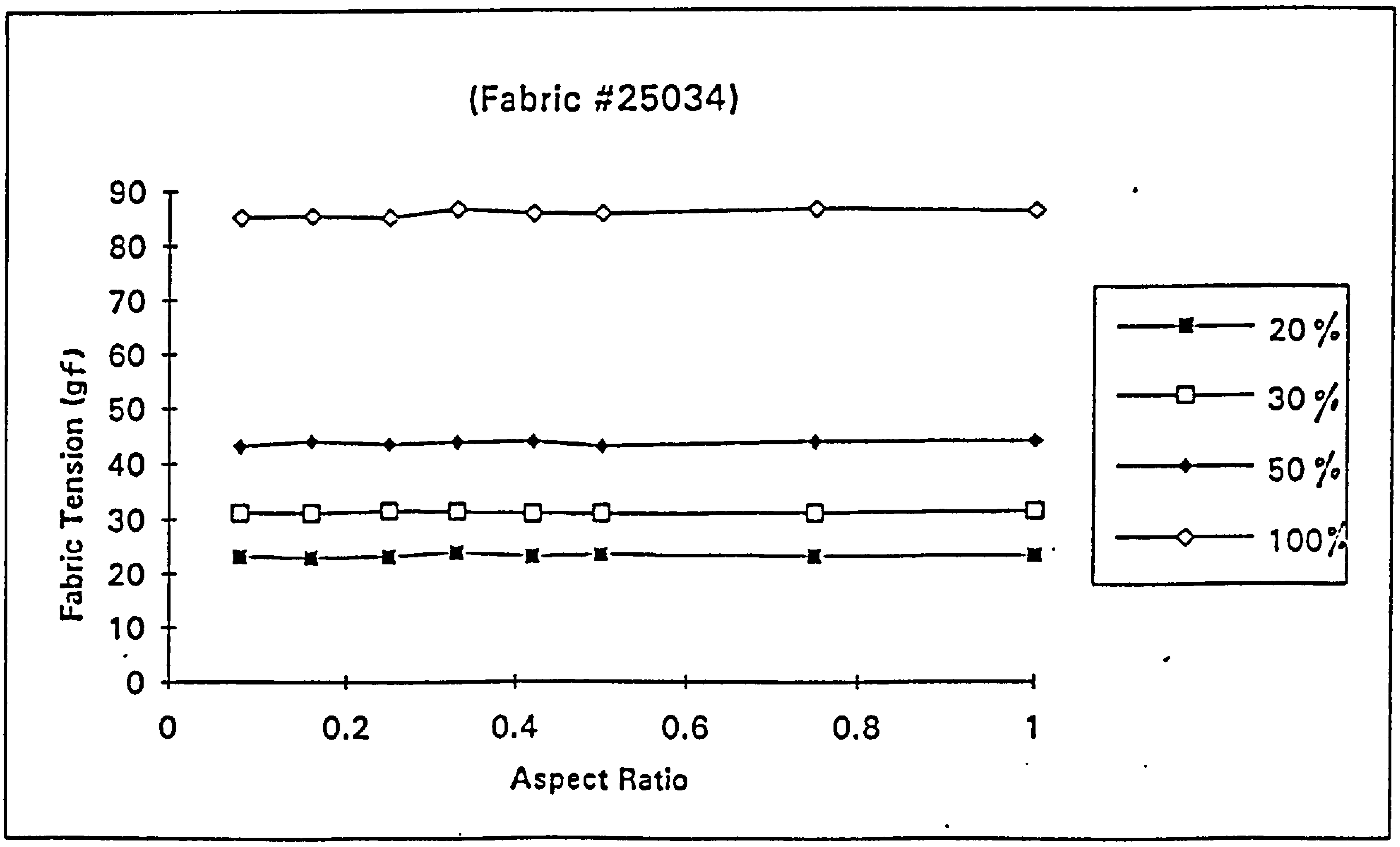
Aspect Ratio	Stretch Percentage (%) 20	30	50	100
1.00	19.0	27.0	45.0	127.2
0.75	19.4	26.9	44.5	125.0
0.50	18.8	26.8	44.0	122.4
0.42	19.0	26.7	44.0	121.5
0.33	19.6	28.0	44.7	122.0
0.25	20.0	28.6	45.3	126.7
0.16	19.8	28.4	46.0	122.5
0.08	19.2	28.0	46.0	124.0

Fabric #25034

Aspect Ratio	Stretch Percentage (%) 20	30	50	100
1.00	23.3	31.4	44.0	86.2
0.75	23.1	31.0	43.9	86.4
0.50	23.5	30.9	43.1	85.6
0.42	23.2	31.0	44.0	85.8
0.33	23.8	31.3	43.8	86.5
0.25	23.1	31.5	43.5	85.0
0.16	23.0	31.2	44.0	85.3
0.08	23.2	31.2	43.2	85.2

Table 3.6 : The Tension Force (gf/cm) of Elastic Fabric Measured at Different Aspect Ratio by Fabric Loop Test (After Waisting Effect is eliminated)





Graph 3.6 The Change of Fabric Tension (g force) Vs Specimen of Different Aspect Ratio at Different Stretch Percentage (by Fabric Loop Test)

3.3.2 Test Results and Discussion

3.3.2.1 Cut-Strip Test

It is observed that if the specimen is stretched to the same percentage, lower tension is found when the guage length of the specimen increases, which means fabric tension decreases when the aspect ratio of the specimen is decreased. This may be because of the waisting effect of the elastic fabric under strain . When a parallel-sided fabric strip is fixed at two ends by flat clamps and is strained up to certain point, the center line of the strip is plainly shorter than the two edges, the waisting results in the edge yarns of the test specimen being stretched more than the central yarns, which means the part of yarns at fabric edges have been strained more than the pre-determined extension, and thus being under greater fabric tension. Such effect is more obvious when the gauge length of the speicmen become shorter, this explains why the tension force is slightly higher when the aspect ratio of the specimen is bigger (see Table 3.4 and Graph 3.5).

The two tested fabrics responded similarly under strain, fabric tension increase slightly when the specimen length decreases, this happens when the specimen is stretched to different stretch percentages (range from 5.3% to 53.8%).

Even though the test results indicated there was a change of fabric tension when the aspect ratio of the specimen was changed from 0.41 to 0.09, such variations is fairly low in terms of coefficient of variation (only between 2.1% - 5.5%). However, the range of aspect ratio to be tested is only within a relatively low value, it should be noted that the actual size of pressure garments normally made in higher aspect ratio, for example, the size of an arm tube pressure garment may be 40cm in width and 15cm in length. In such a case, the aspect ratio is around 3 to 4. Based on the indication of the test results, if the aspect ratio of the specimen becomes very high, it is quite possible to have a significant difference in tension force if the stretch percentage of the specimen remains constant.

3.3.2.2 Fabric Loop Test

On straining the fabric loop under these conditions, it was found that the specimen contracted evenly in width, very little if any waisting effect occurring when the specimen is stretched within low extension range (e.g., within the range 20% to 50%). However, waisting on specimen was observed when it was stretched up to 100% extension, and the waisting effect was more obvious when the length of the stretched specimen was relatively shorter, this means the use of rotating pin clamp can help to minimise the amount of waisting on a stretched specimen, but not eliminate waisting of specimens completely.

With reference to the test results shown at Table 3.5, when the aspect ratio of the specimen was changed, the tension force per unit width of the tested specimen was similar, only the specimen of higher aspect ratio (0.1 and 0.75) showed higher tension force when the specimen were stretched to 100% extension. This was due to the waisting effect that occurred at the specimen of higher aspect ratio particularly when they were stretched to a high extension.

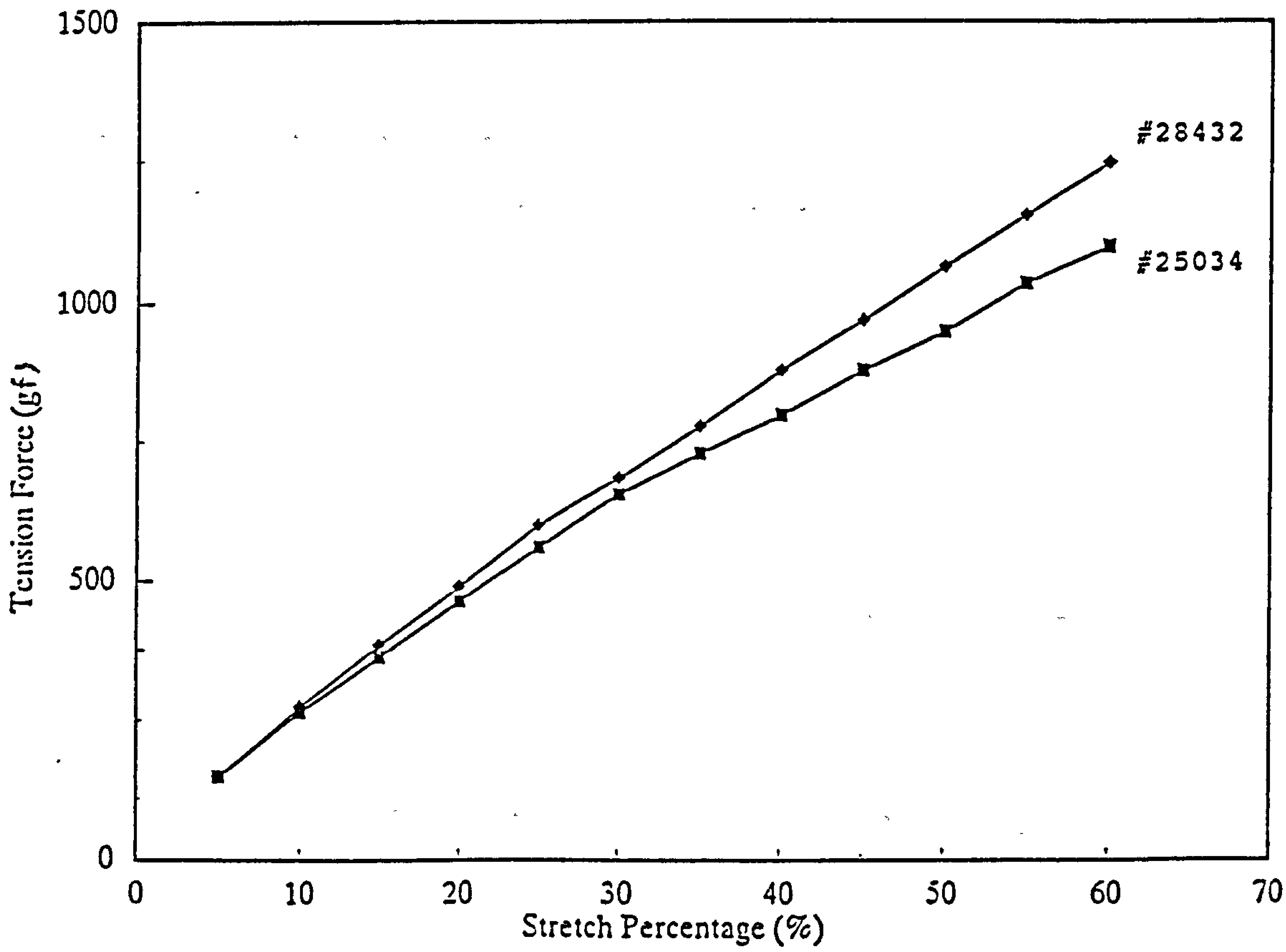
If the waisting of the stretched fabric loop was eliminated by hand or by rotating the pin of the clamp manually, it was noted that the tension per unit width on the tested specimens of different aspect ratios are all similar (see Table 3.6 and Graph 3.6 for the test results). As shown in Graph 3.6, the relationship between the fabric tension per unit width and the aspect ratio of the specimen is almost a horizontal line, the results is very constant when the specimen is stretched within the range 20% to 50%, only small variations appear when the fabric is stretched up to 100%, this indicates that a change of specimen size does not affect the tension force exerted on the test fabrics even if the aspect ratio be increased to higher values. Therefore, even though the range of aspect ratio for the test is fairly low (only between 0.08 - 1), the test result is still valid for the normal size of pressure garment in actual use.

The findings observed in test 3.3.1.1 and test 3.3.1.2 are not the same, such difference is mainly due to the use of a rotating pin clamp to replace the normal flat fabric clamp of the tensile testing machine. The use of the pin clamp for the test 3.3.2.2 can help to minimise waisting appearing on the tested specimen, thus the fabric strip was permitted to contract uniformly in width as it is stretched, instead of holding it out to its original width at the jaw during the testing. Even though the design of the rotating pin clamp is not perfect, friction between the fabric loop and the pin surface still exists and waisting was only found at specimens of higher aspect ratio and under high extension. The test results showed that, if without the effect of waisting on the stretched specimen, tension force per unit width of the specimen at different aspect ratios becomes fairly constant.

3.4 DISCUSSION OF THE EXPERIMENTAL RESULTS

3.4.1 Comparision Between the Pressure from Experimental Tube Model and the Theory

Based on the tension measured from the fabric strip by the Instron Tensile Strength machine (see Table 3.1), the load-extension curve of the fabric #28432 and #25034 can be plotted (see Graph 3.7).

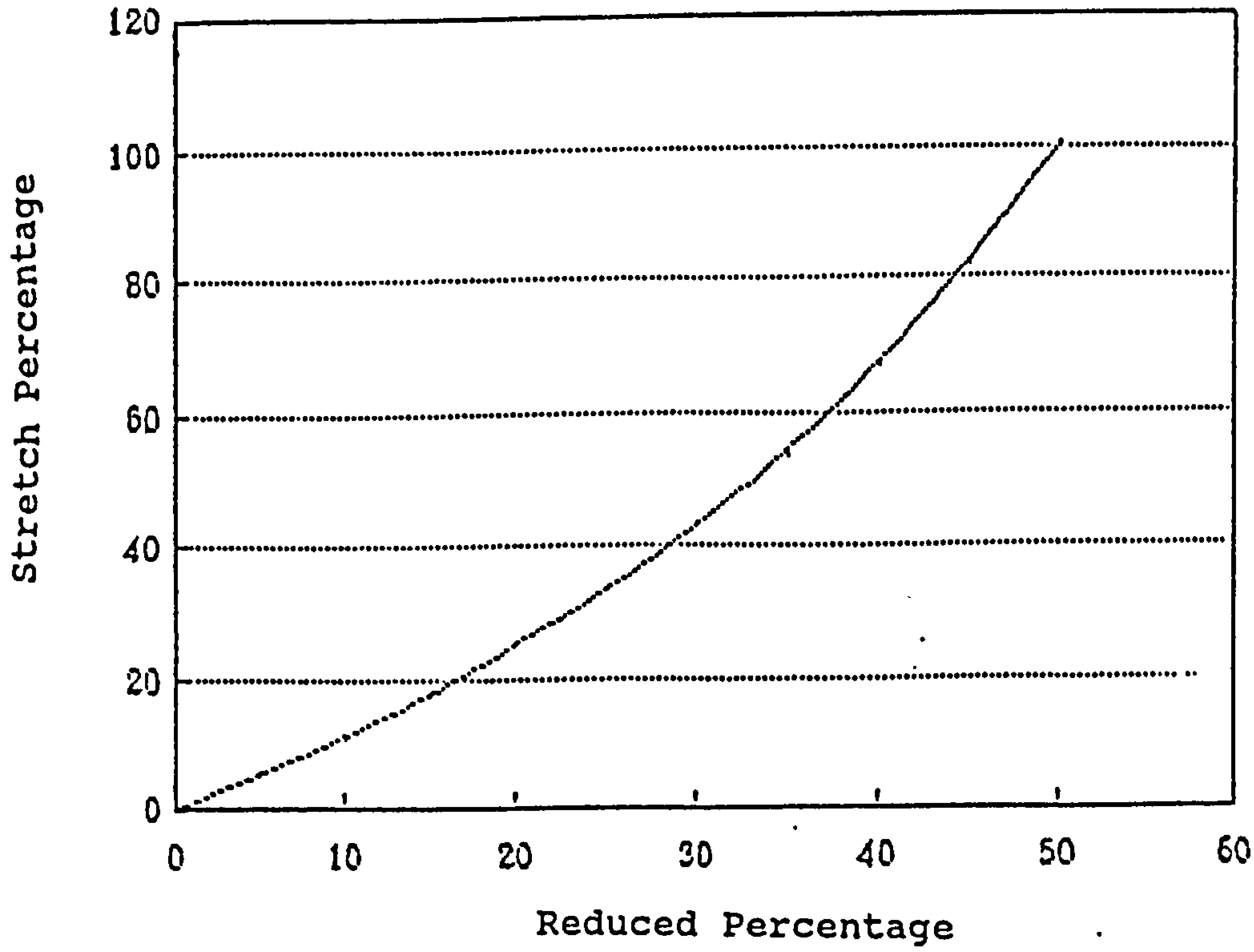


Graph 3.7 The Load-Extension Curves of Fabric #28432 & Fabric #25034

Since the stretch % of garment = reduced % /(100-reduced %) ,if a tubular pressure garment is cut 25% smaller than the size of a tube or limbs, when it is placed on the tube or limbs, it will undergo a stretch of 33%. The relationship betwen the stretch percentage and the reduced percentage of garment are presented at Table 3.7 and Graph 3.8.

Reduced Percentage	Stretch Percentage
5	5.3
10	11.1
15	17.6
20	25
25	33.3
30	42.9
35	53.8
40	66.7
45	81.8
50	100

Table 3.7 Table of Converting the Reduced % of Pressure Garment into the Stretch %



Graph 3.8 The Relationship Between the Stretch Percentage of Elastic Fabric and the Reduced Percentage of Pressure Garment

If we compare the pressure measured from the experimental tube model to the pressure worked out from the theoretical calculation based on the tensile force of the elastic fabric, we need to find the tension produced by these elastic fabrics at extensions of 5.3%, 11.1%, 17.6%, 25%, 33.3%, 42.9%, and 53.8%. (The tubular pressure garment will be stretched to the same extension as they are made 5%, 10%, 15%, 20%, 25%, 30%, and 35% smaller than the size of tube or limbs). The tension force of the fabric #28432 and #25034 at these extensions can be worked out from their load-extension curves (the result is shown at Table 3.8).

Stretch Percentage

	5.3	11.1	17.6	25	33.3	42.9	53.8
Fabric #28432	208	303	431	600	739	928	1142
Fabric #25034	189	296	408	560	680	841	1025

Table 3.8 The Tension Force (gm. force) of the Elastic Fabric at Various Extensions (worked out from the Load-Extension Curve Graph 3.7)

Based on the fabric tension as shown at Table 3.8, the possible interface pressure on different sizes of curvature was calculated (see Table 3.9) to make comparison with those measured from the cylindrical tube model (see Table 3.3). The difference of interface pressure between the tube model and the theory at different garment reduced percentage are compared by Graph 3.9.

Fabric #28432

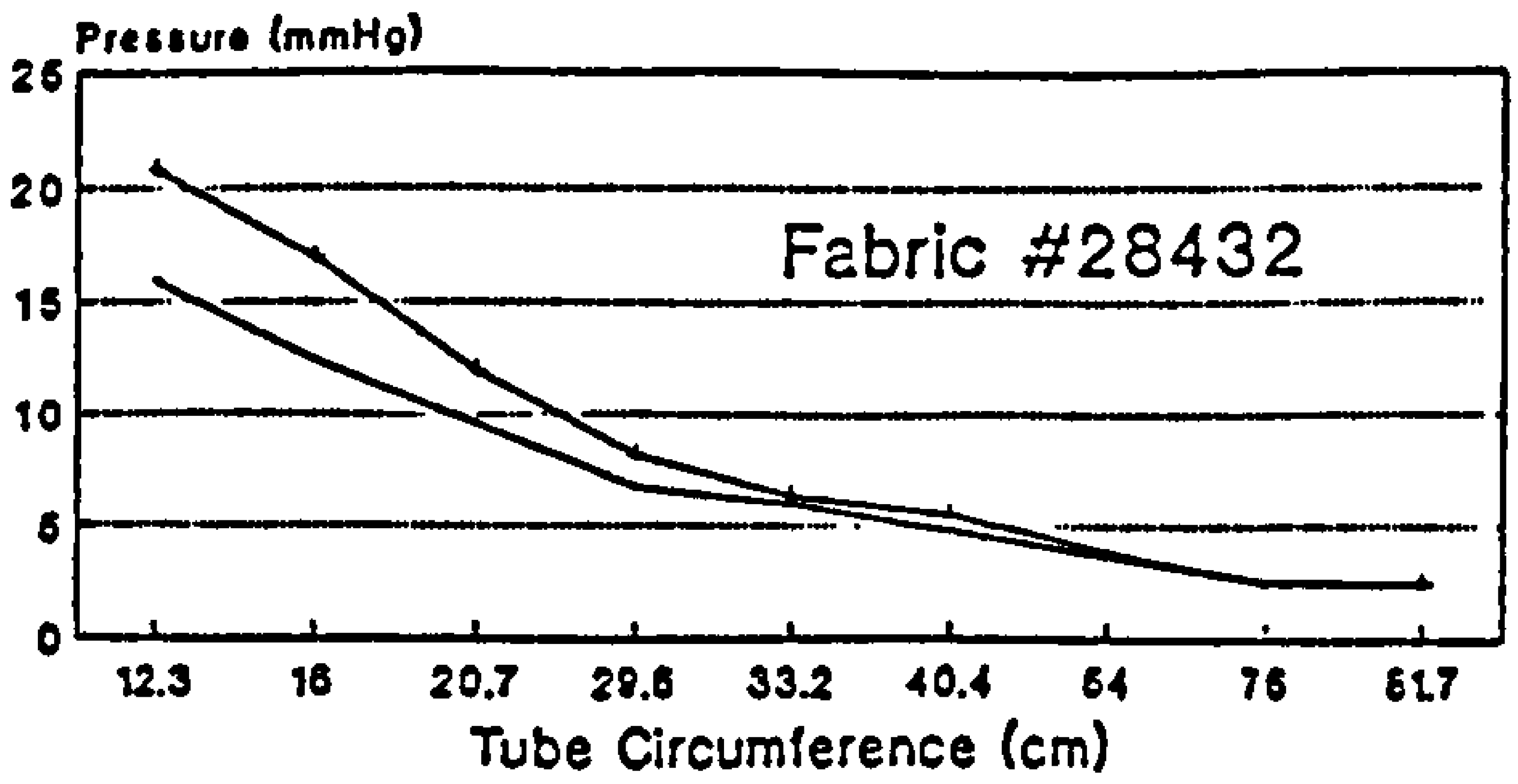
Tube Circumference (cm)	Stretch Percentage of Garment 5.3	11.1	17.6	25	33.3	42.9	53.8
12.3	15.9	23.1	32.9	45.8	56.4	70.9	87.2
16	12.5	18.2	25.9	36.	44.4	55.7	68.6
20.7	9.7	14.1	20	27.8	34.3	43.1	53
29.6	6.8	9.8	14	19.5	24	30.1	37.1
33.2	6	8.8	12.5	17.4	21.4	26.9	33.1
40.4	4.9	7.2	10.2	14.2	17.5	22	27.1
54	3.7	5.4	7.7	10.7	13.2	16.5	20.3
76	2.6	3.8	5.5	7.6	9.4	11.7	14.5
81.7	2.5	3.6	5.1	7.1	8.7	10.9	13.5

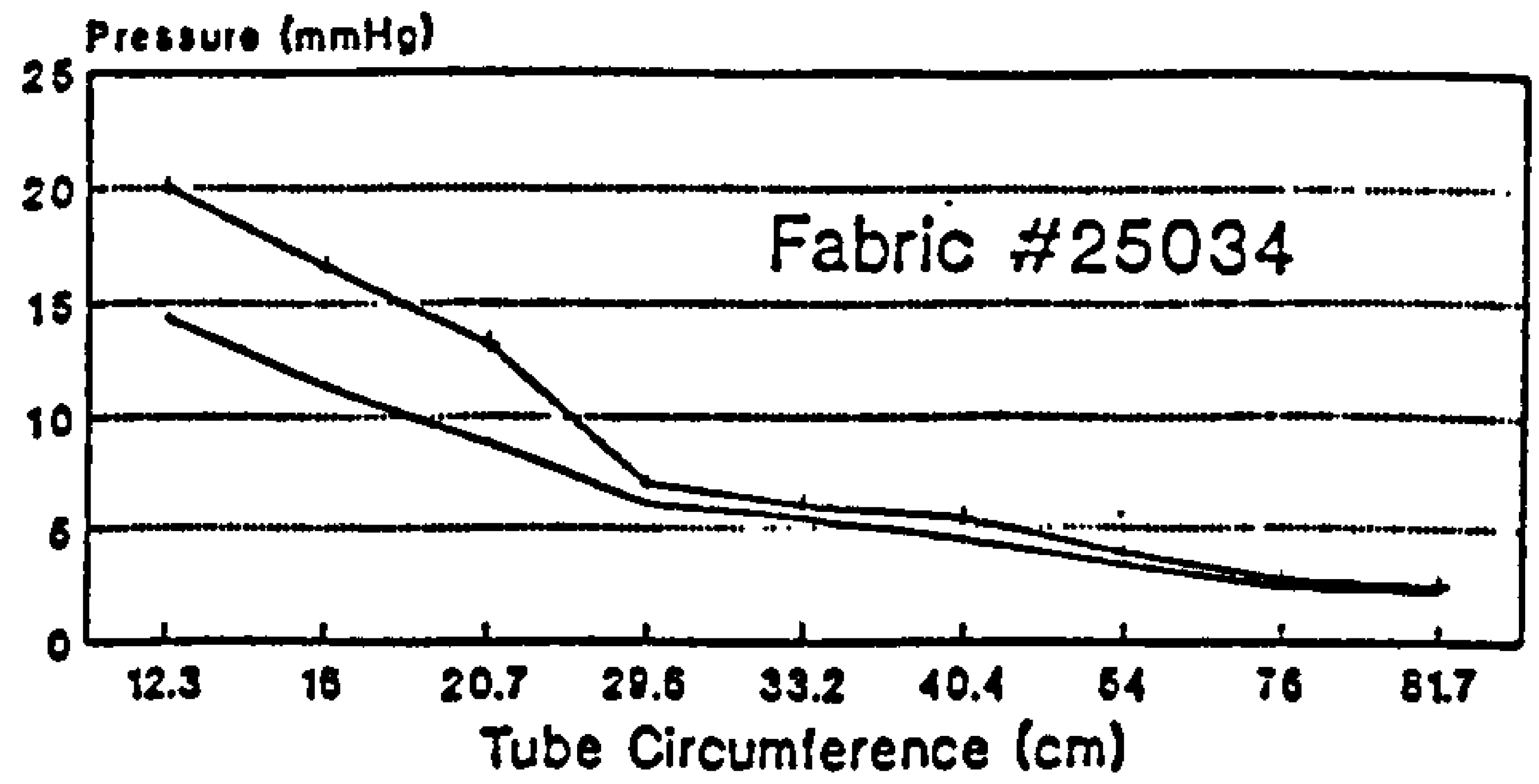
Fabric #25034

Tube Circumference (cm)	Stretch Percentage of Garment 5.3	11.1	17.6	25	33.3	42.9	53.8
12.3	14.4	23.3	31.7	42.8	51.9	64.2	78.3
16	11.4	18.3	24.9	33.6	40.8	50.5	61.6
20.7	8.8	14.2	19.3	26.	31.6	39	47.6
29.6	6.1	9.9	13.5	18.2	22.1	27.3	33.3
33.2	5.5	8.8	12	16.2	19.7	24.4	29.7
40.4	4.5	7.2	9.9	13.3	16.1	20	24.3
54	3.4	5.4	7.4	10.	12.1	15	18.3
76	2.4	3.9	5.3	7.1	8.6	10.6	13
81.7	2.2	3.6	4.9	6.6	8	9.9	12.1

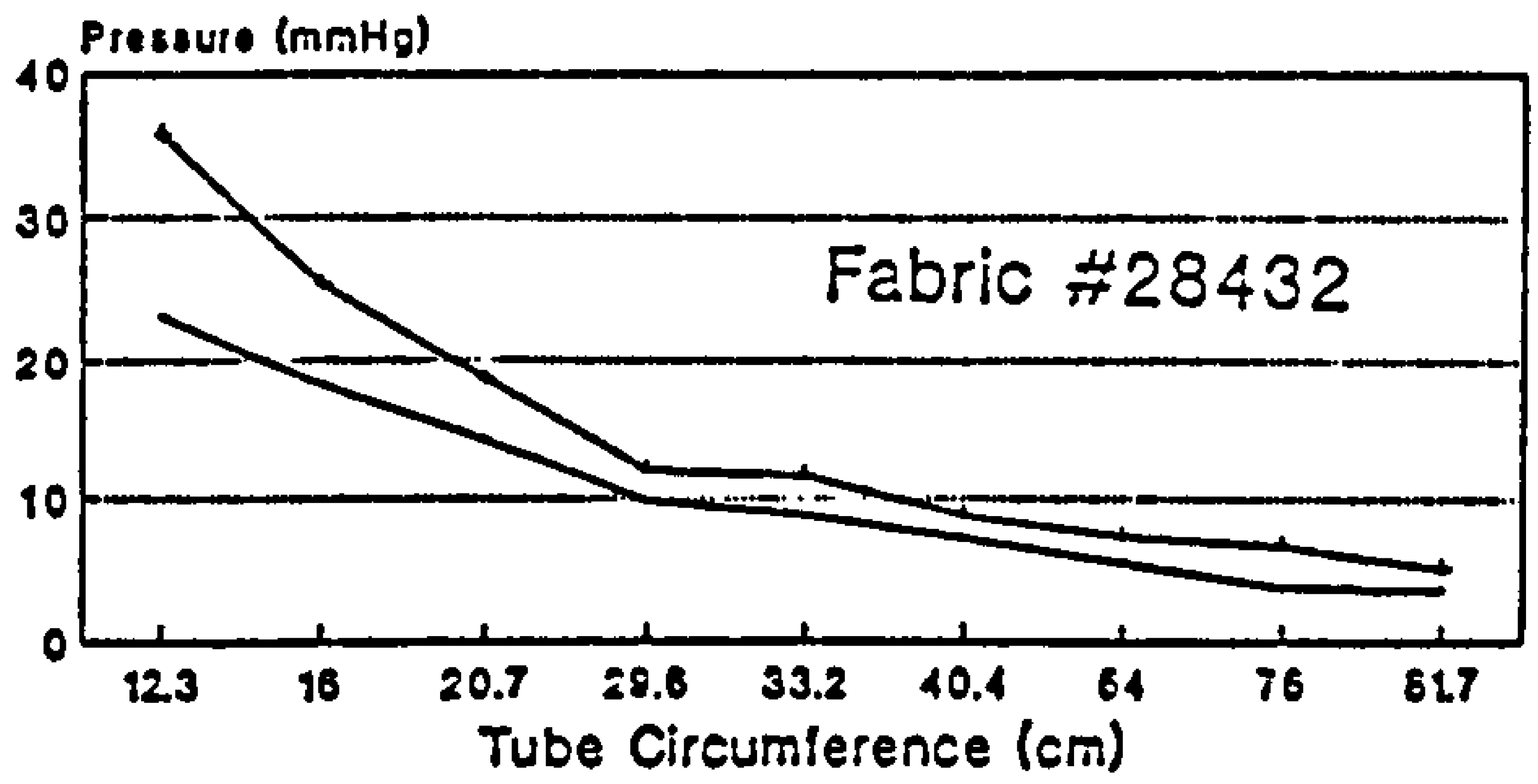
Table 3.9 Possible Pressure Produced on Tube Model Based on Theoretical Calculation

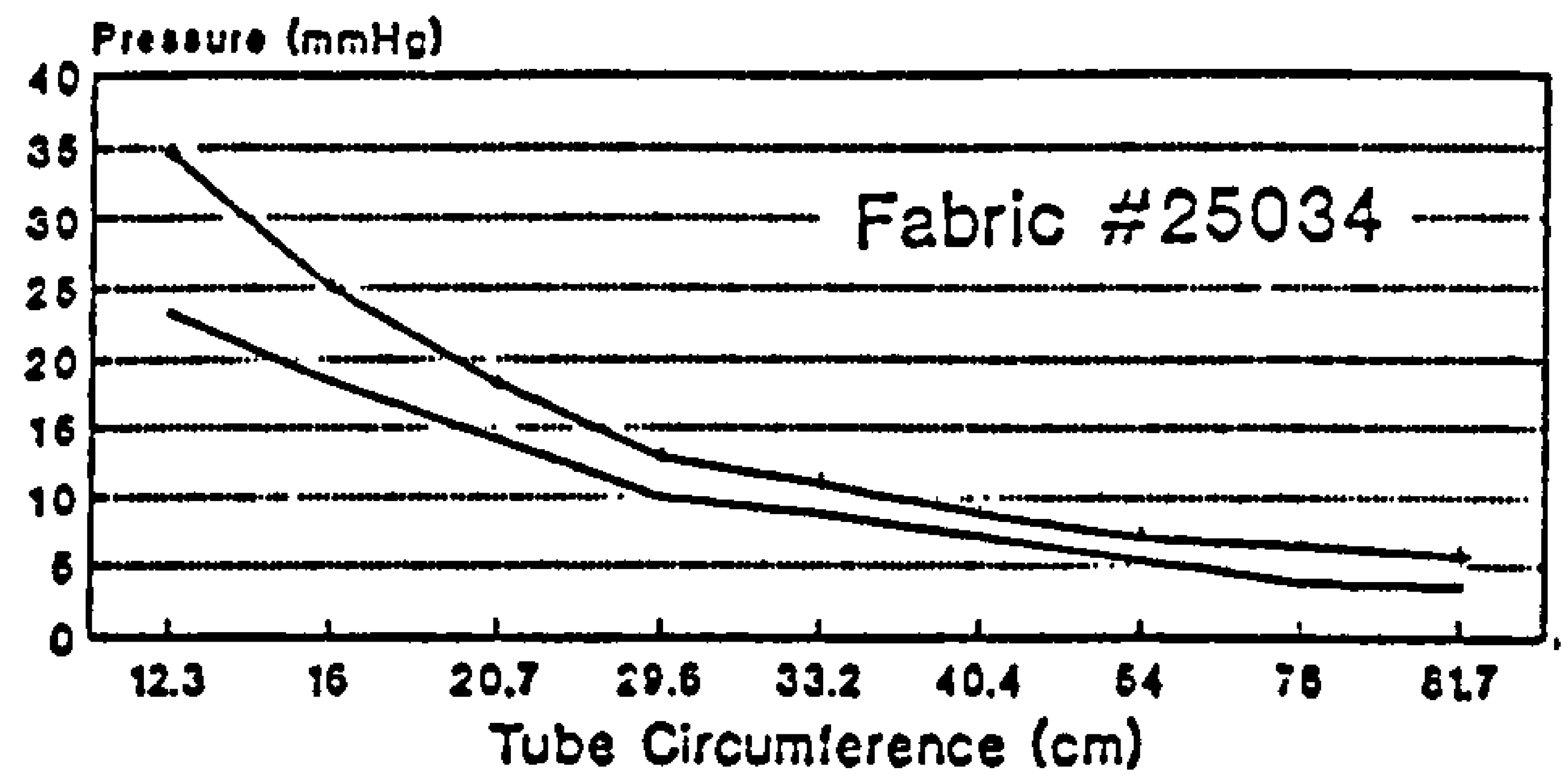
5% Reduction of Size of Pressure Garment



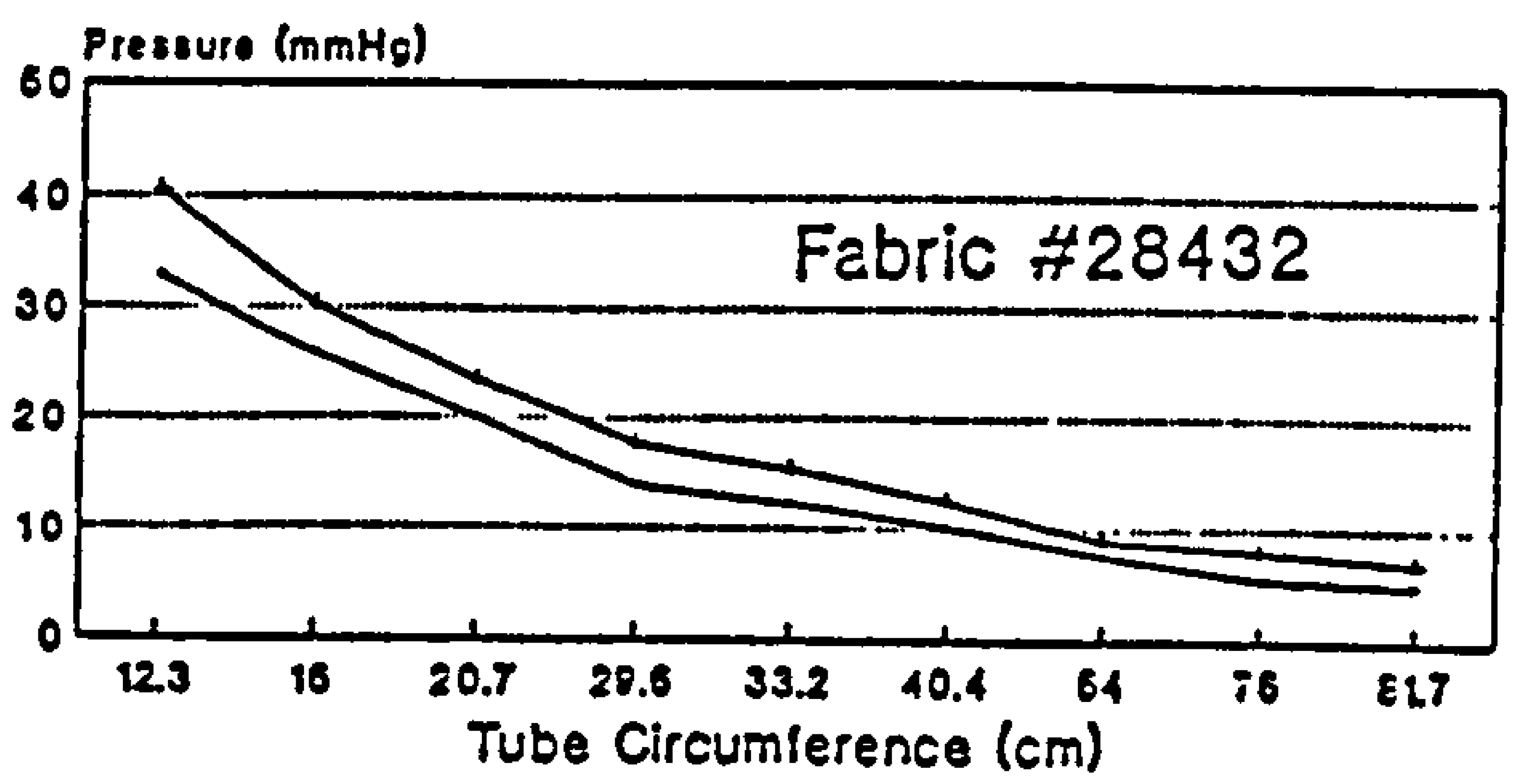


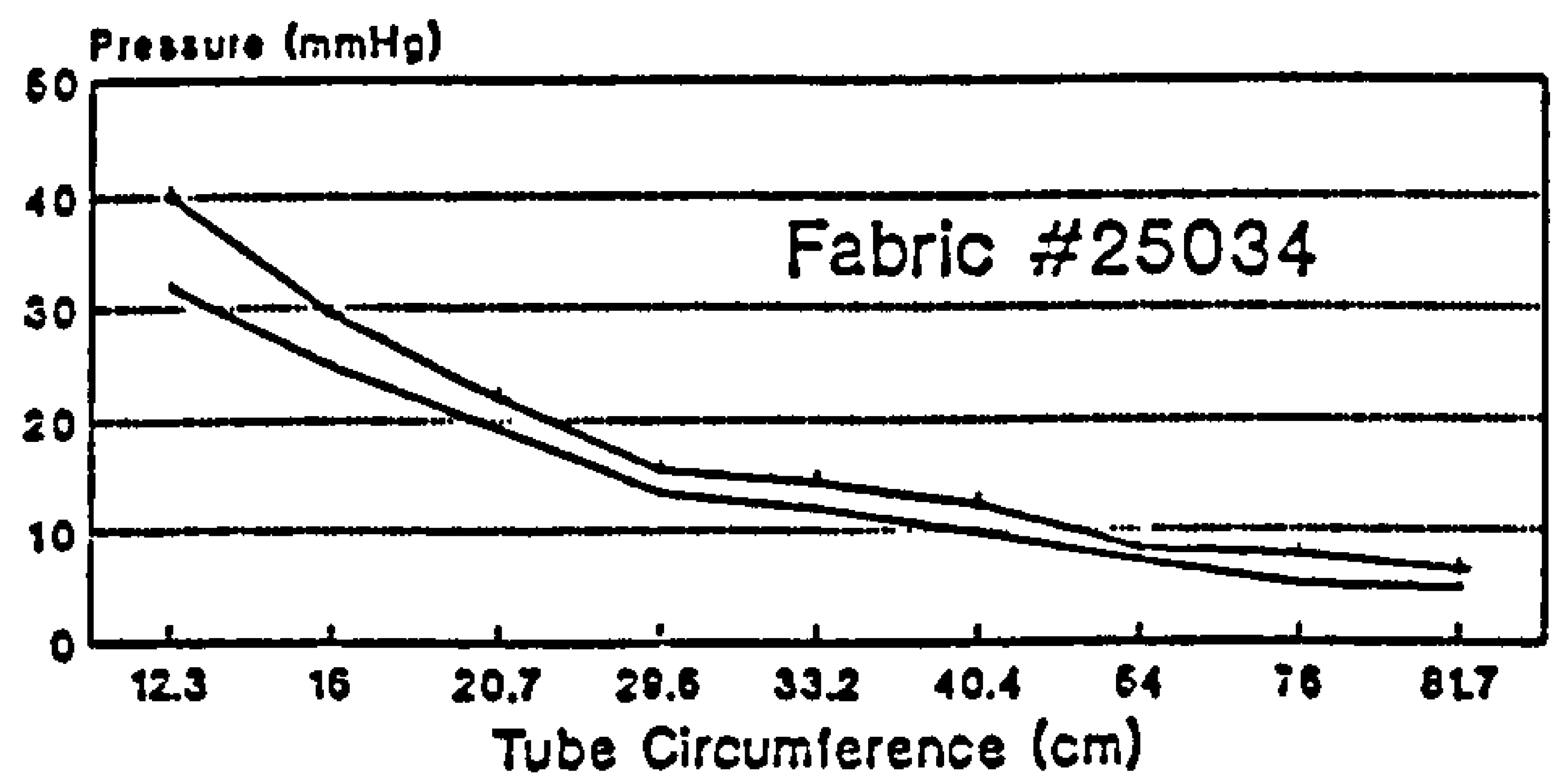
10%Reduction of Size of Pressure Garment



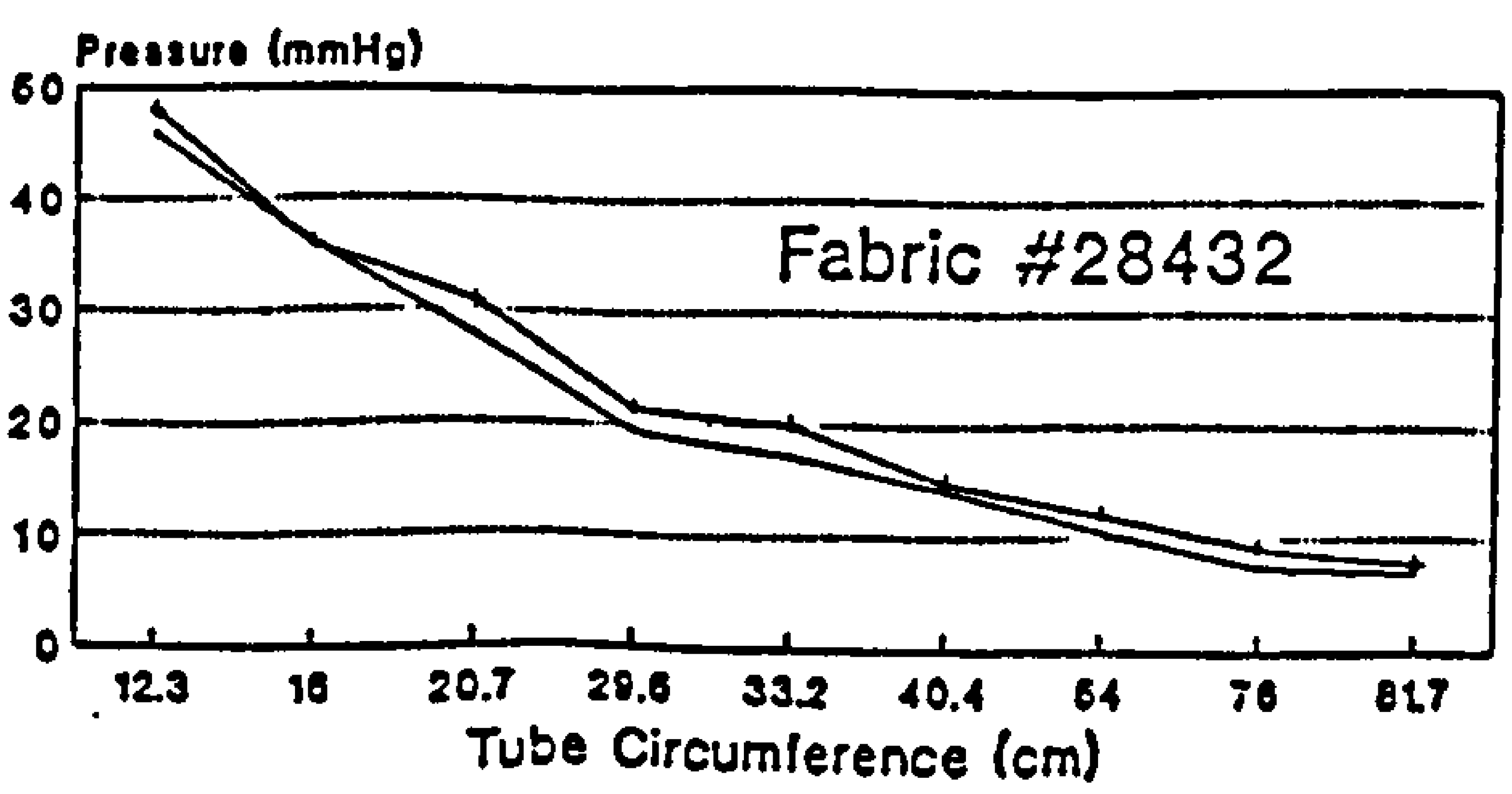


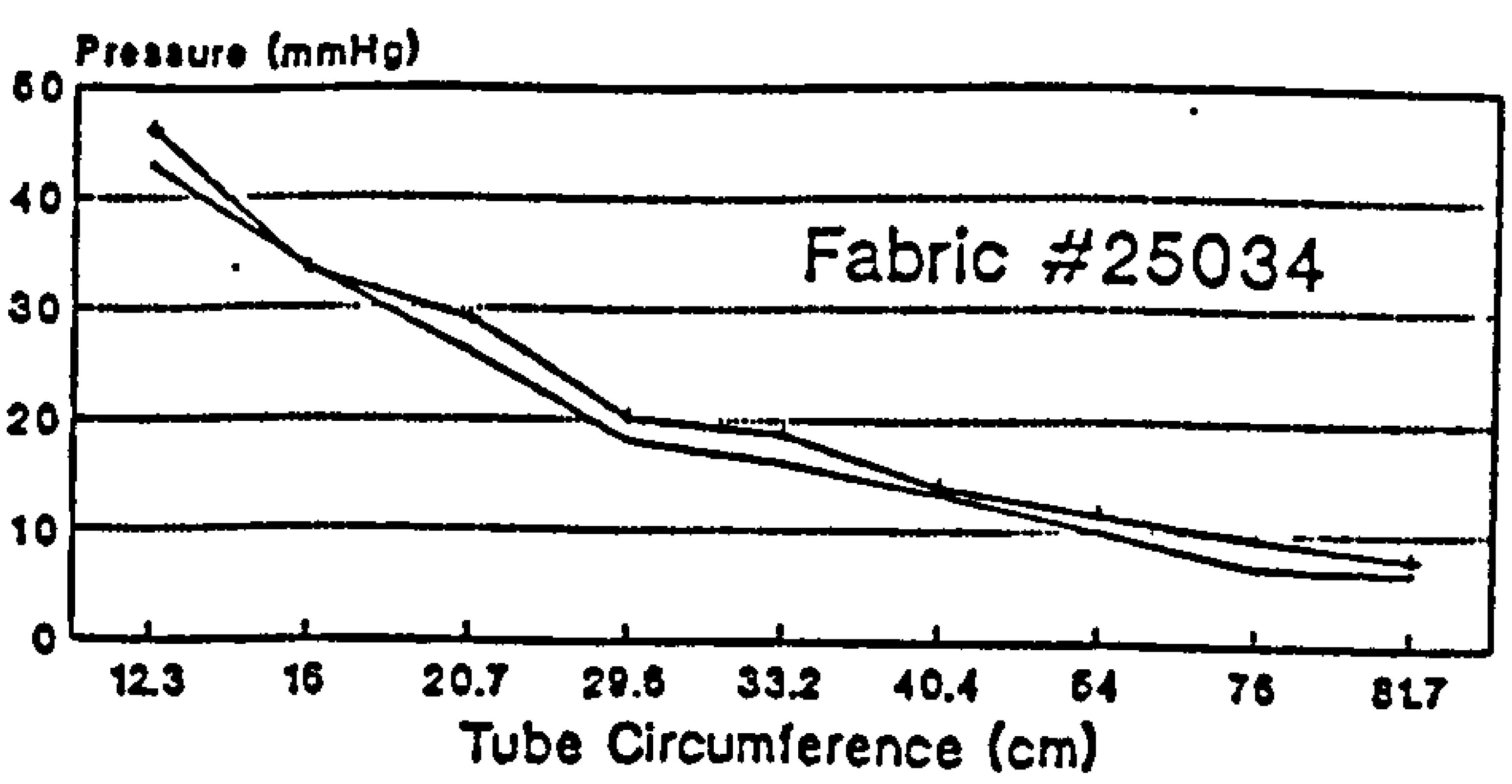
15%Reduction of Size of Pressure Garment





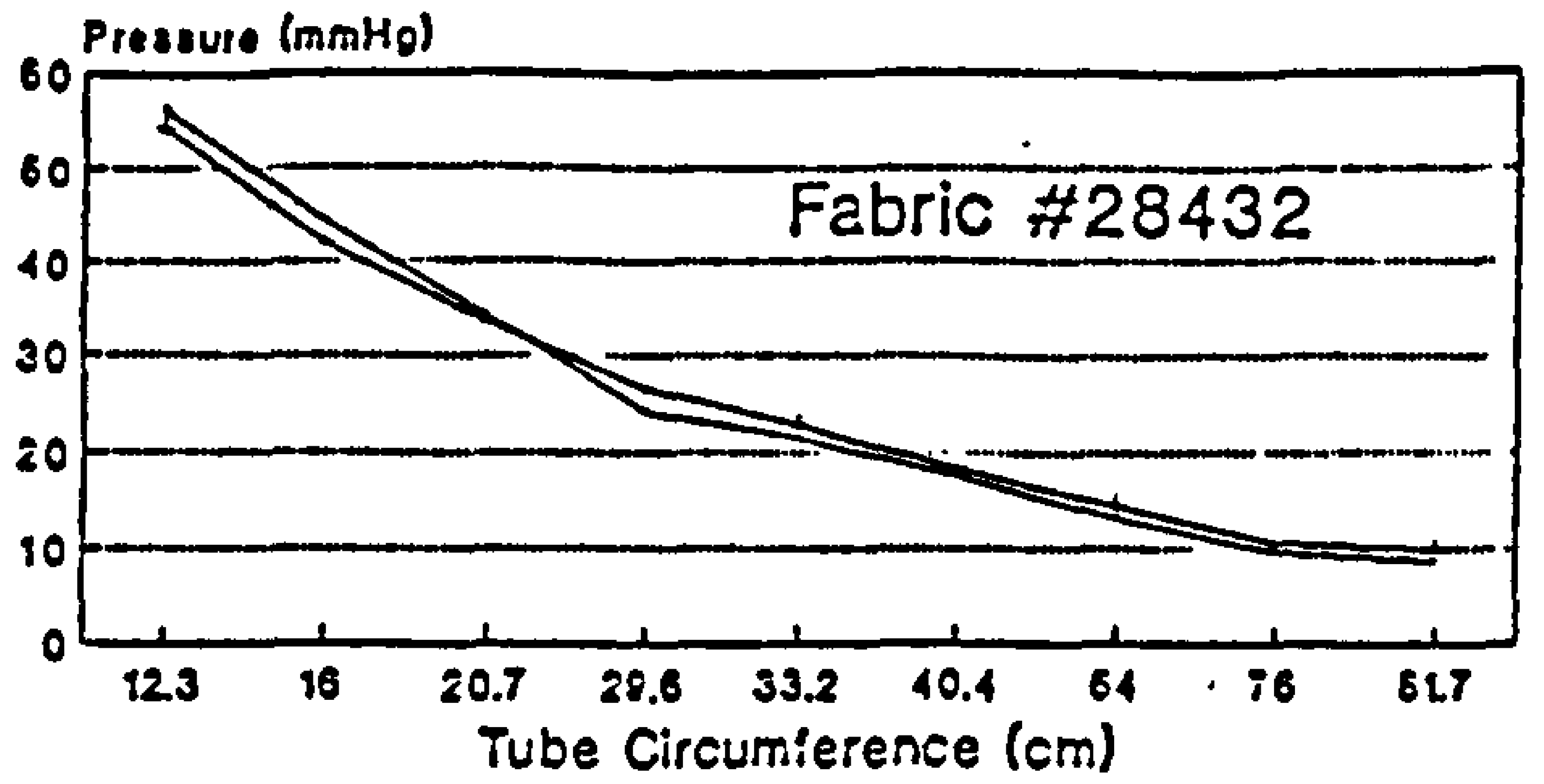
20%Reduction of Size of Pressure Garment

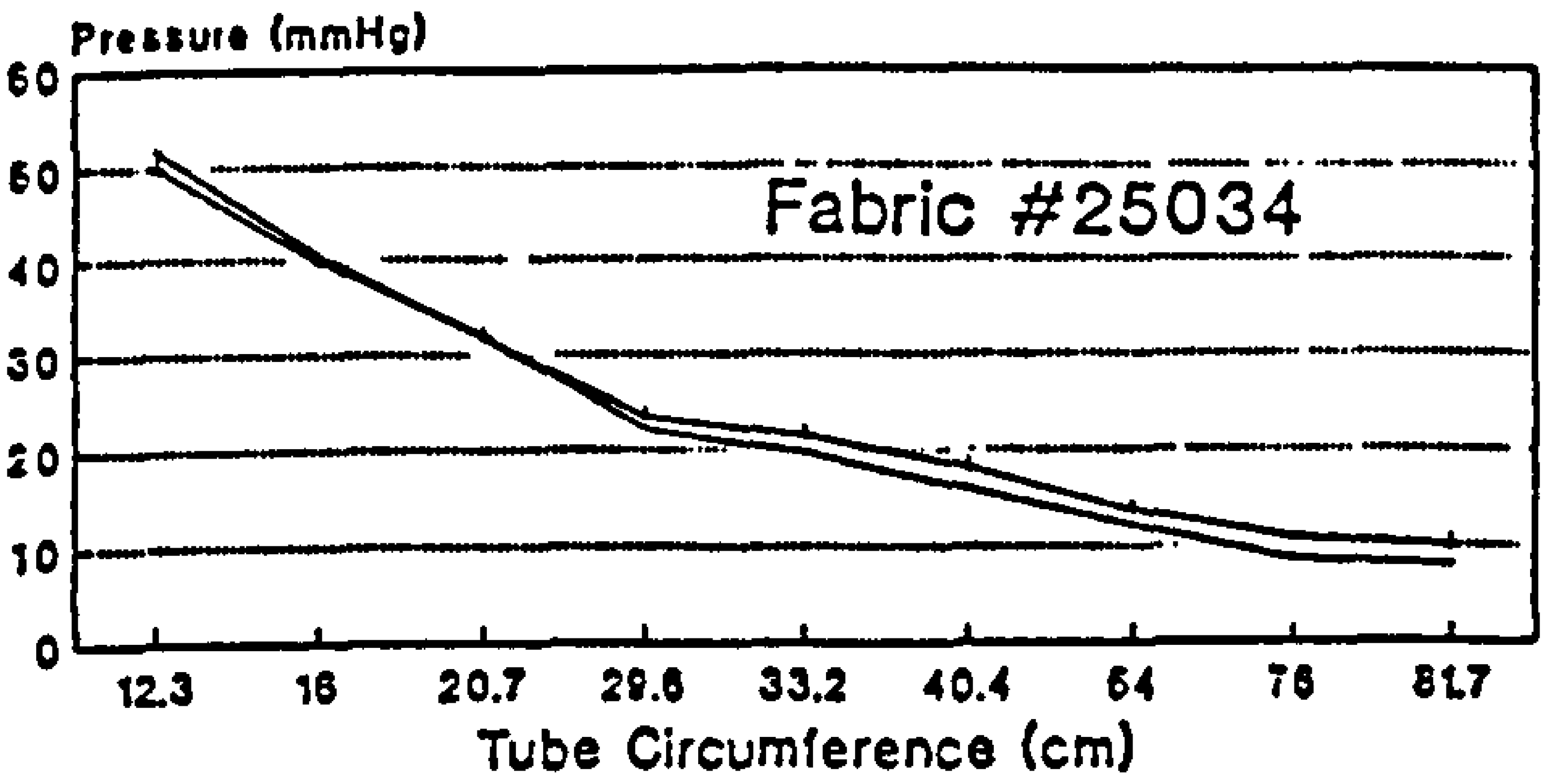




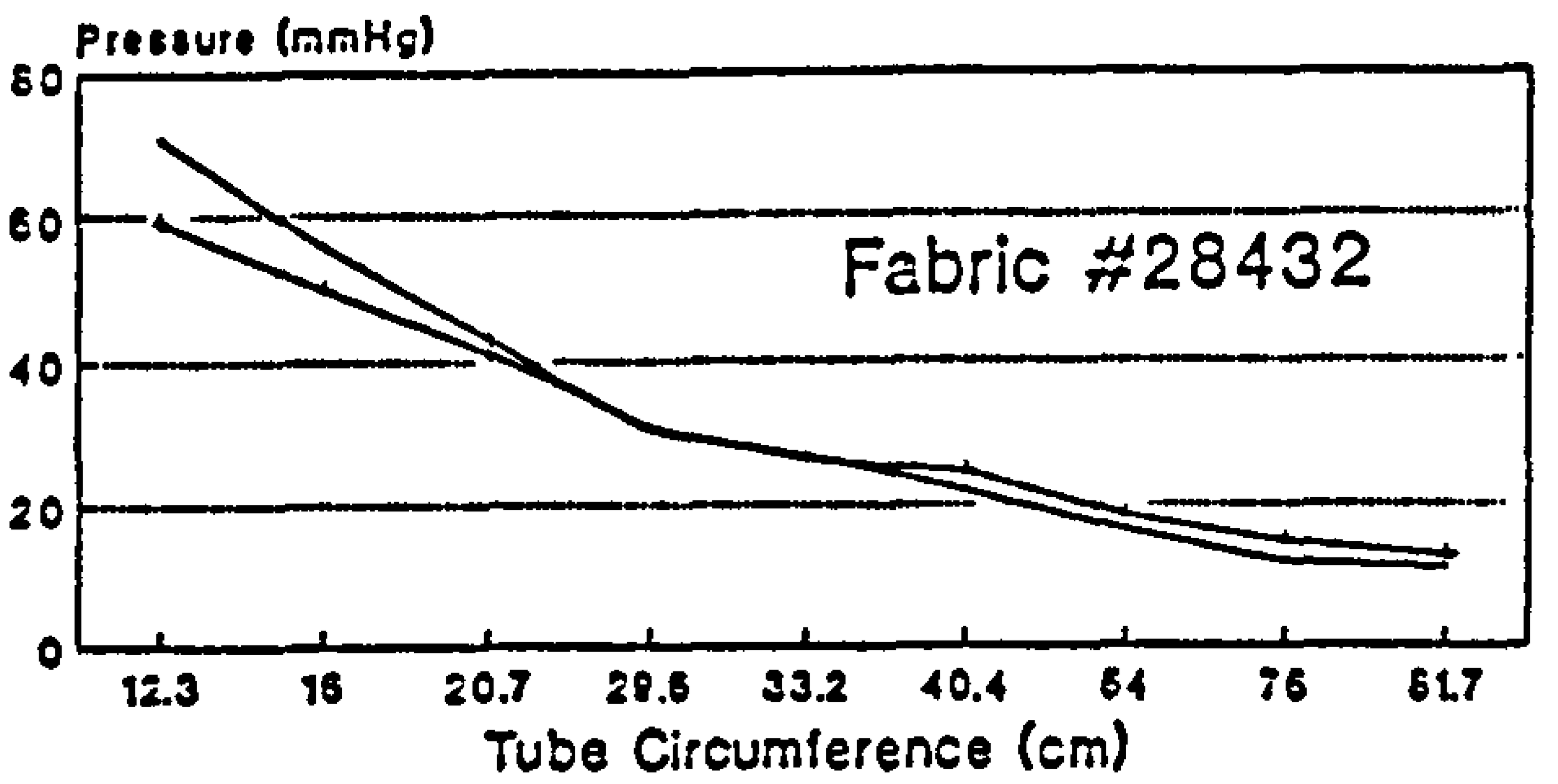
Graph 3.9 The Comparison of Interface Pressure (mmHg) Between the Tube Models and the Theoretical Calculation at Different Percentage of Reduction (Reduced%) of Pressure Garment

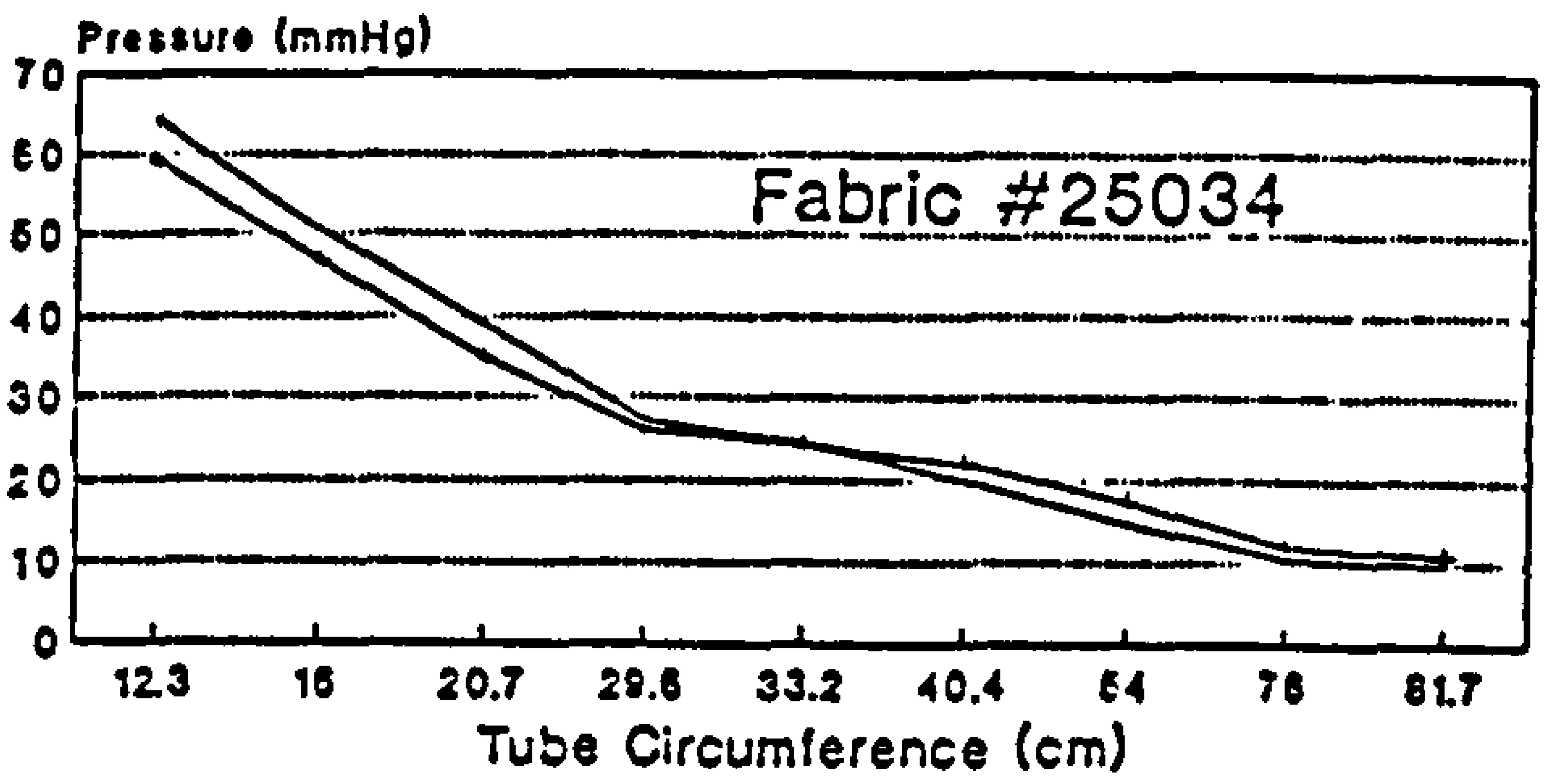
25%Reduction of Size of Pressure Garment



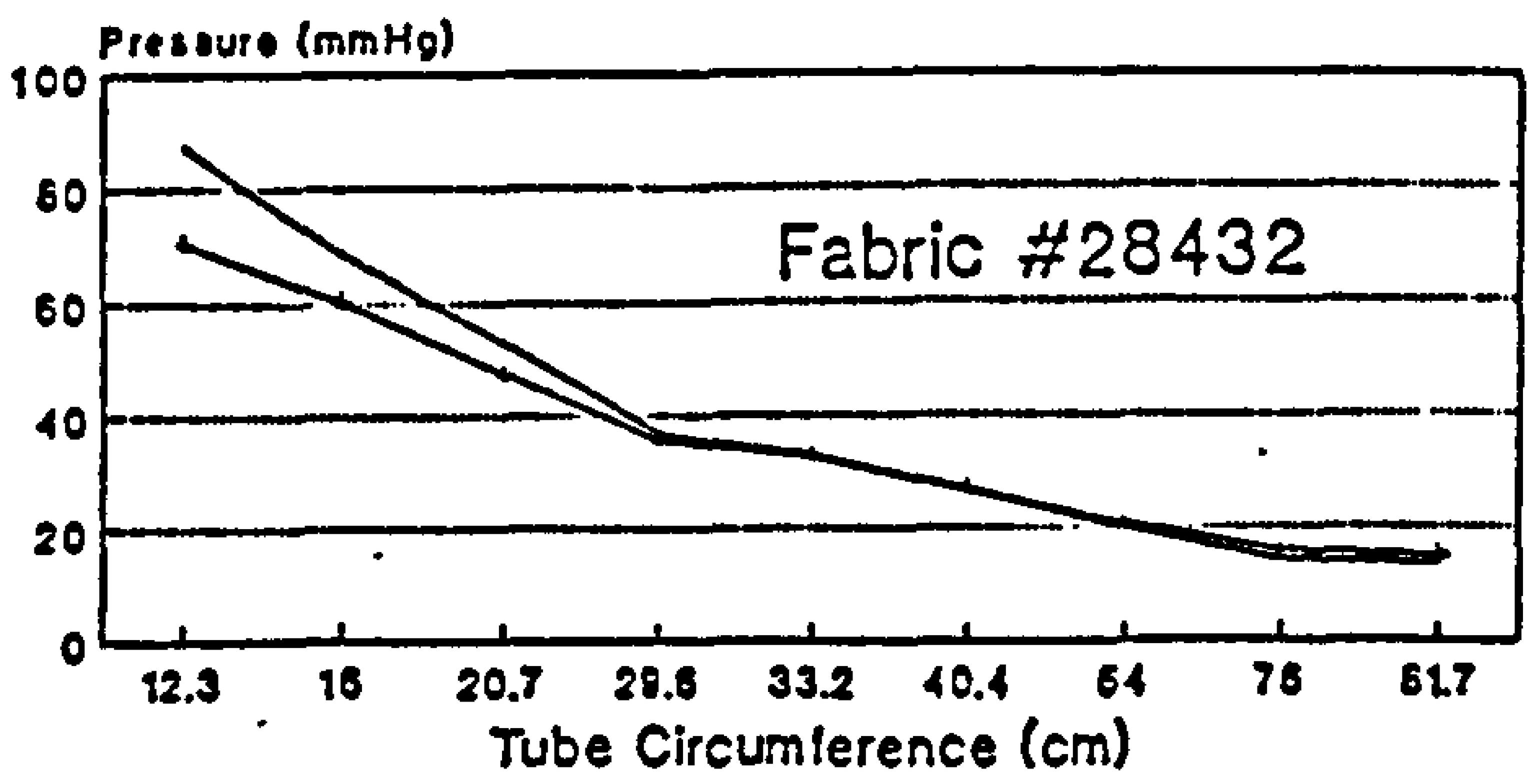


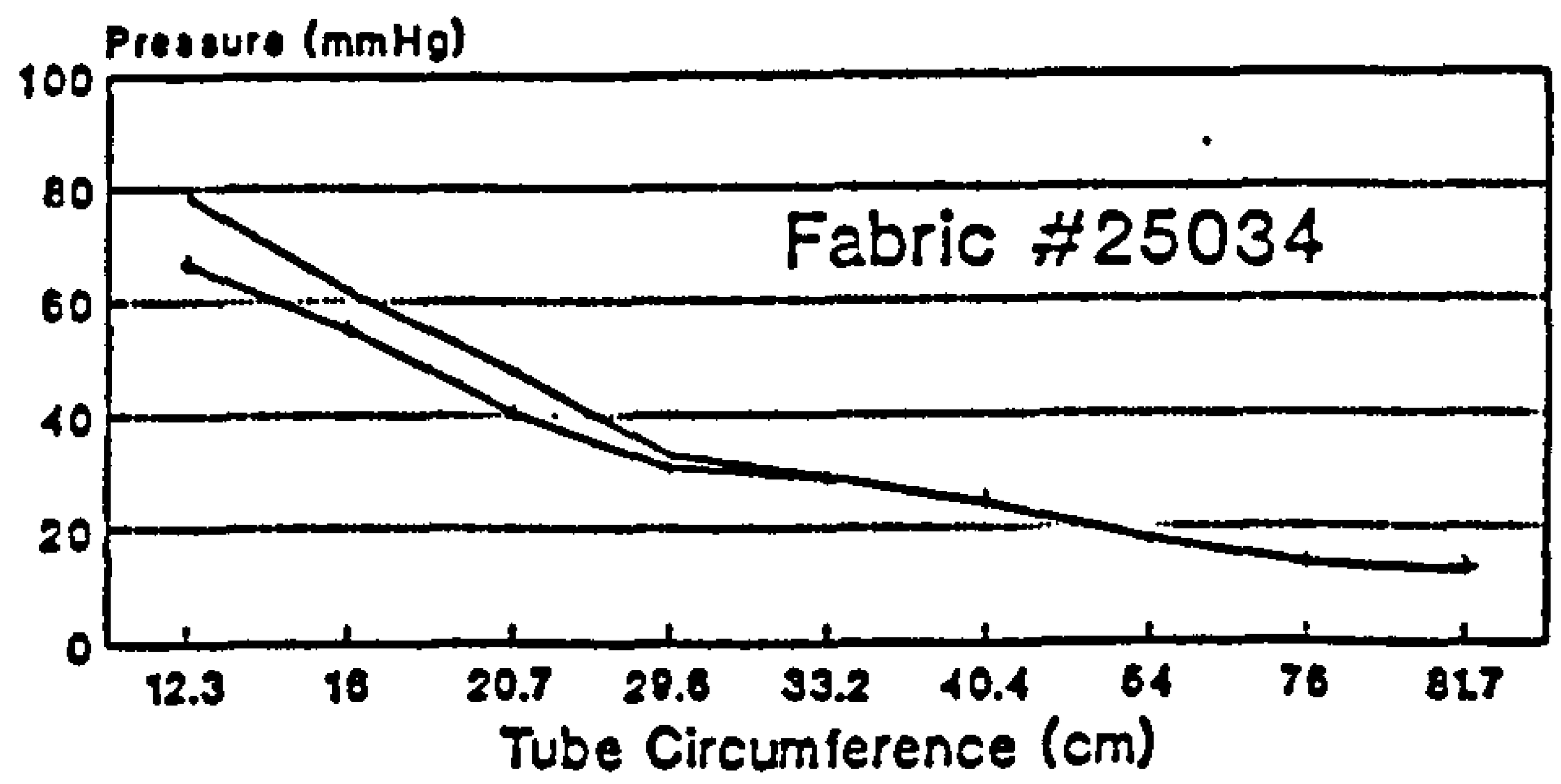
30%Reduction of Size of Pressure Garment





35%Reduction of Size of Pressure Garment





Model —+— Series 1 Theory. —— Series 2

Graph 3.9 The Comparison of Interface Pressure (mmHg) Between the Tube Models and the Theoretical Calculation at Different Percentage of Reduction (Reduction %) of Pressure Garment

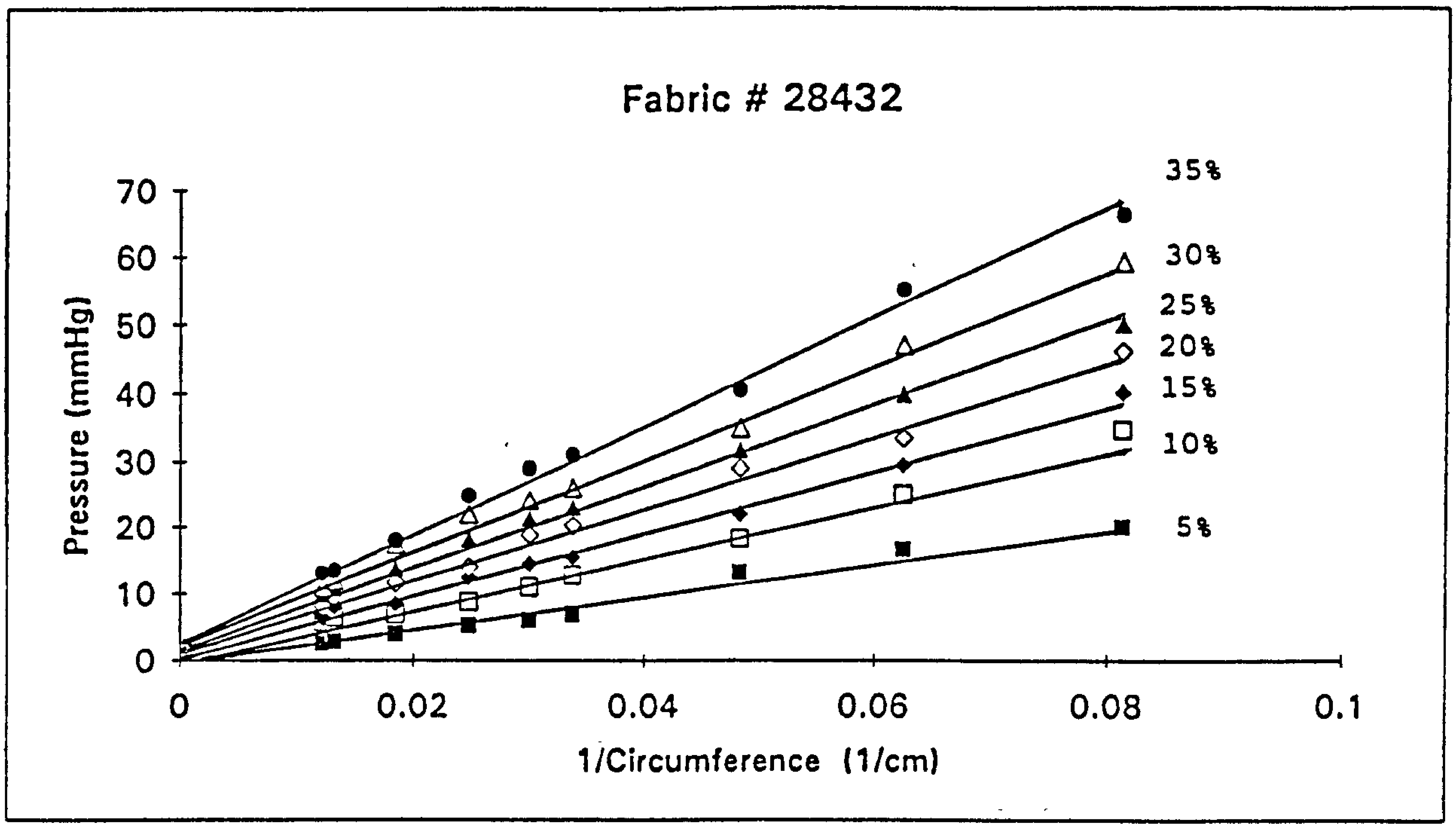
From the results shown in Table 3.9 and Graph 3.9 , it is observed that the pressures calculated from theory have a similar behaviour as those measured from the tube models. They both have great changes on pressure when the circumference of the tube is small, while the pressure change is comparatively smaller when the circumference of the tube becomes bigger.

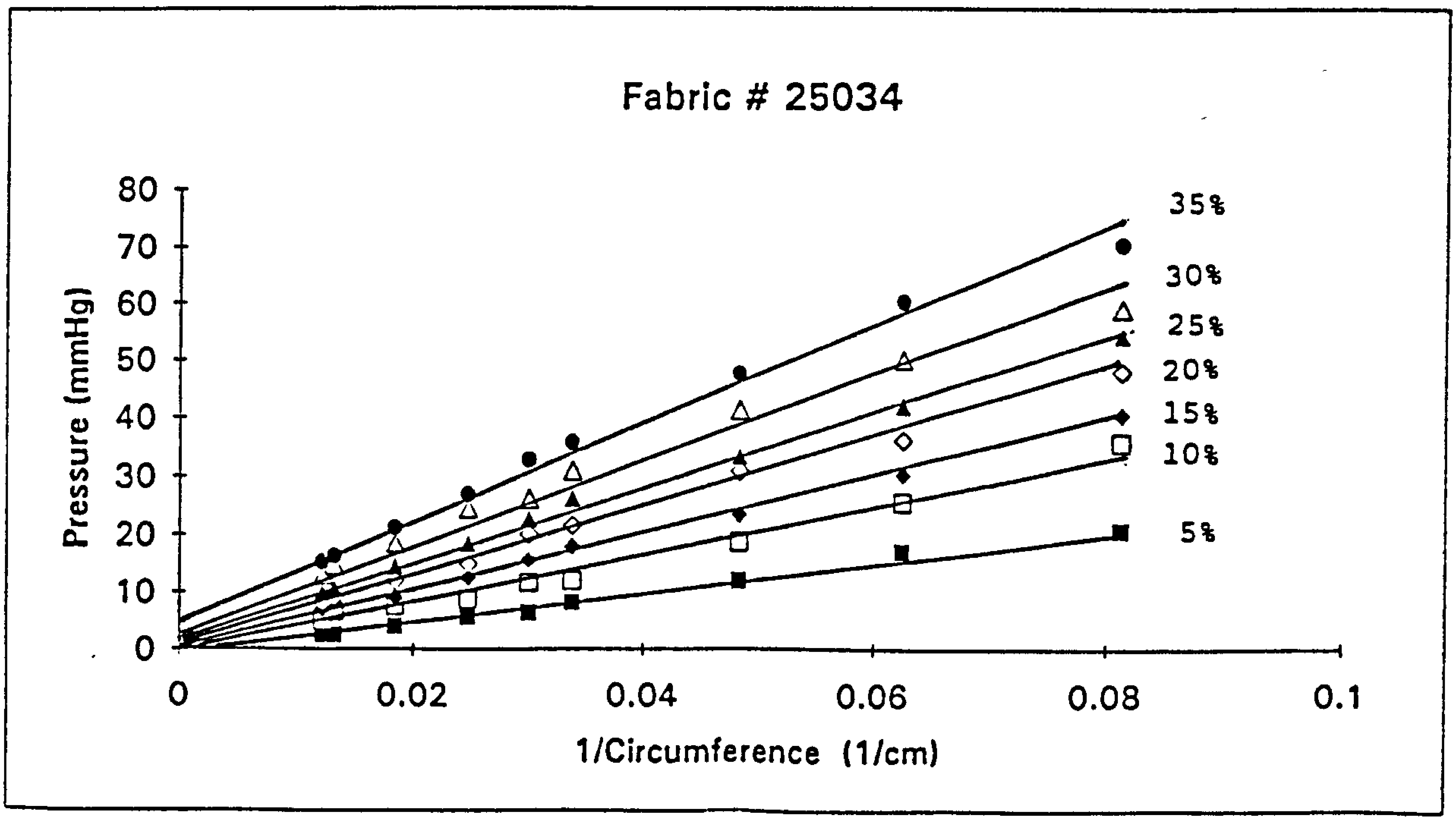
In general, the experimental-determined pressure of both fabrics (#28432 and #25034) are a little greater (about 2-5mmHg) than calculated values, and very near to calculated in the case of larger size of tubes (i.e., tube circumference range from 20.7cm to 81.7cm) particularly to the medium range of garment stretch (i.e. 20 -25 percentage of reduction). Only the pressure obtained from smallest tube model (i.e. 12.3 cm circumference) shows greater variations; for example, the pressure at 5.3% extension (or 5% reduction) is about 5mmHg higher than the theory , but the pressure at higher stretch percentage (e.g. 33.3 - 53.8%) is lower than the theoretical calculation.

For mathematical simplicity, the equation Pressure $\propto$ (Tension/Radius) assumes the interface pressure varies with the radius only, the fabric tension is also assumed uniform over the interface surface and there is no friction between the garment and the surface of curvature. In reality, interface pressure varies in many ways. One advantage of the experimental data over the theoretical calculation is that it is processed under simulated actual wear condition, the garment samples are constructed with seams and it is compressed on the tube surface in the way as they are normally put on human body.

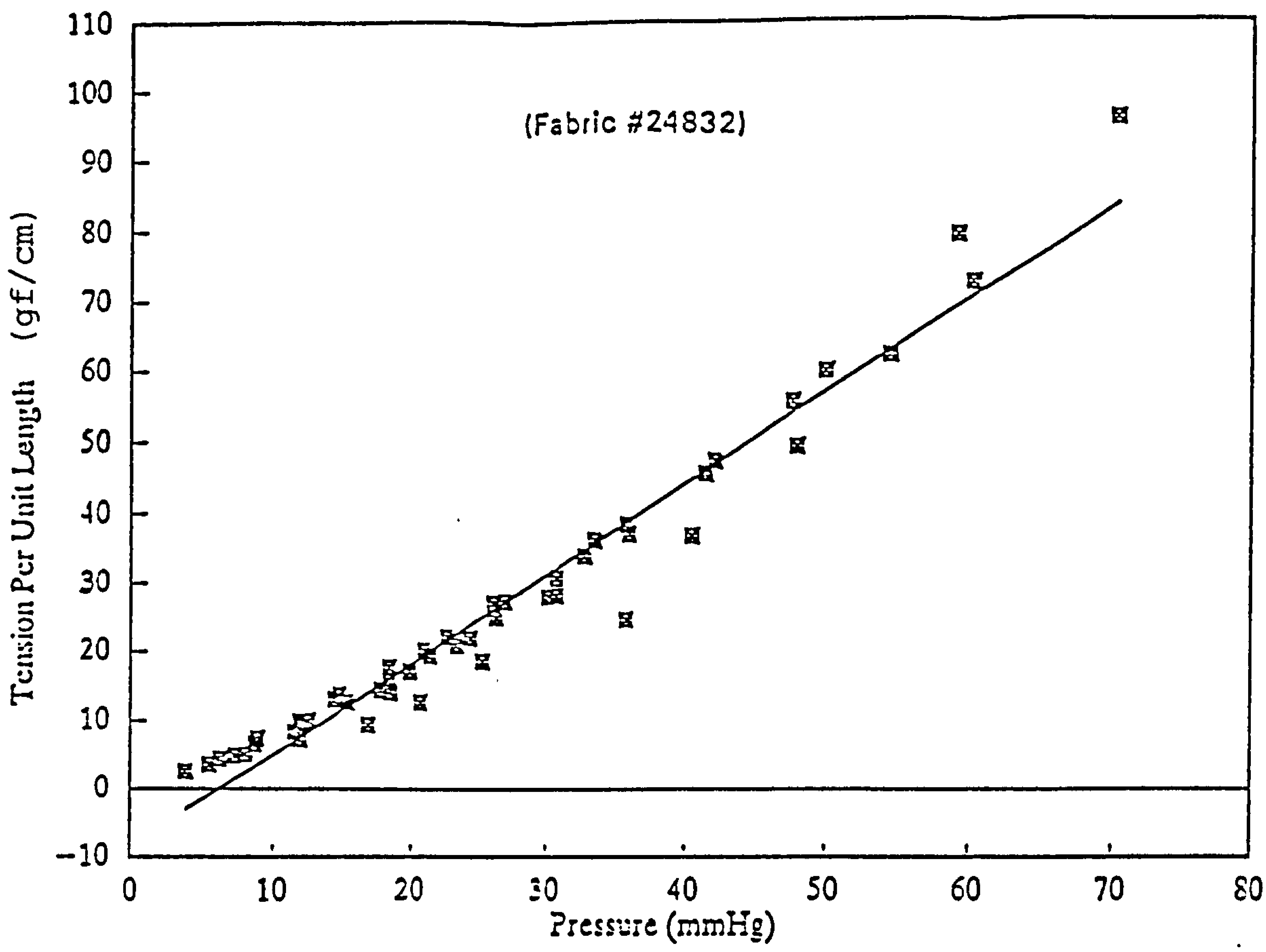
Based on the experimental data collected from the tube models (as shown in Table 3.3), a graph of pressure against 1/Circumference (see Graph 3.10) gives a straight line through the origin as would have been expected from the theory. This shows that : Pressure $\propto$ 1/Circumference.

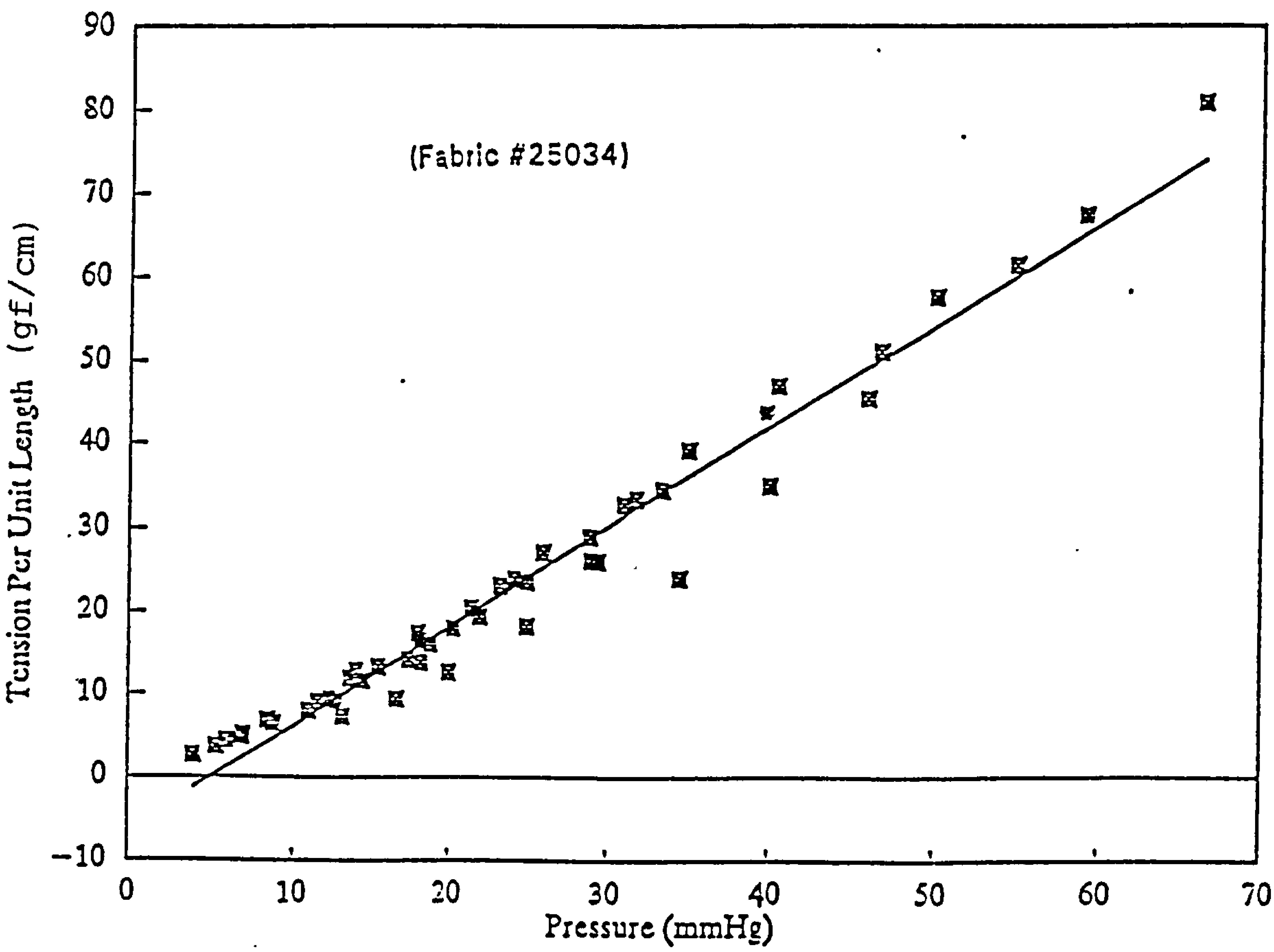
To investigate the relationships between Pressure and Fabric Tension, we can now plot a graph of Tension / Circumference against Pressure (see Graph 3.11). Most of the data points that lies on the graph 3.11 are linear, indicating that the pressure is proportional to the tension of the fabric at the experimental range of extension. Some exceptional cases were found when the pressure was higher than 40mmHg but, since the range of pressure required for treatment lies within 10-35mmHg, the set of data beyond 40mmHg is beyond the interest of study. Therefore other graphs were plotted to indicate the relationship between Fabric Tension against Pressure focusing on the range 5-40mmHg (as shown in Graph 3.12).



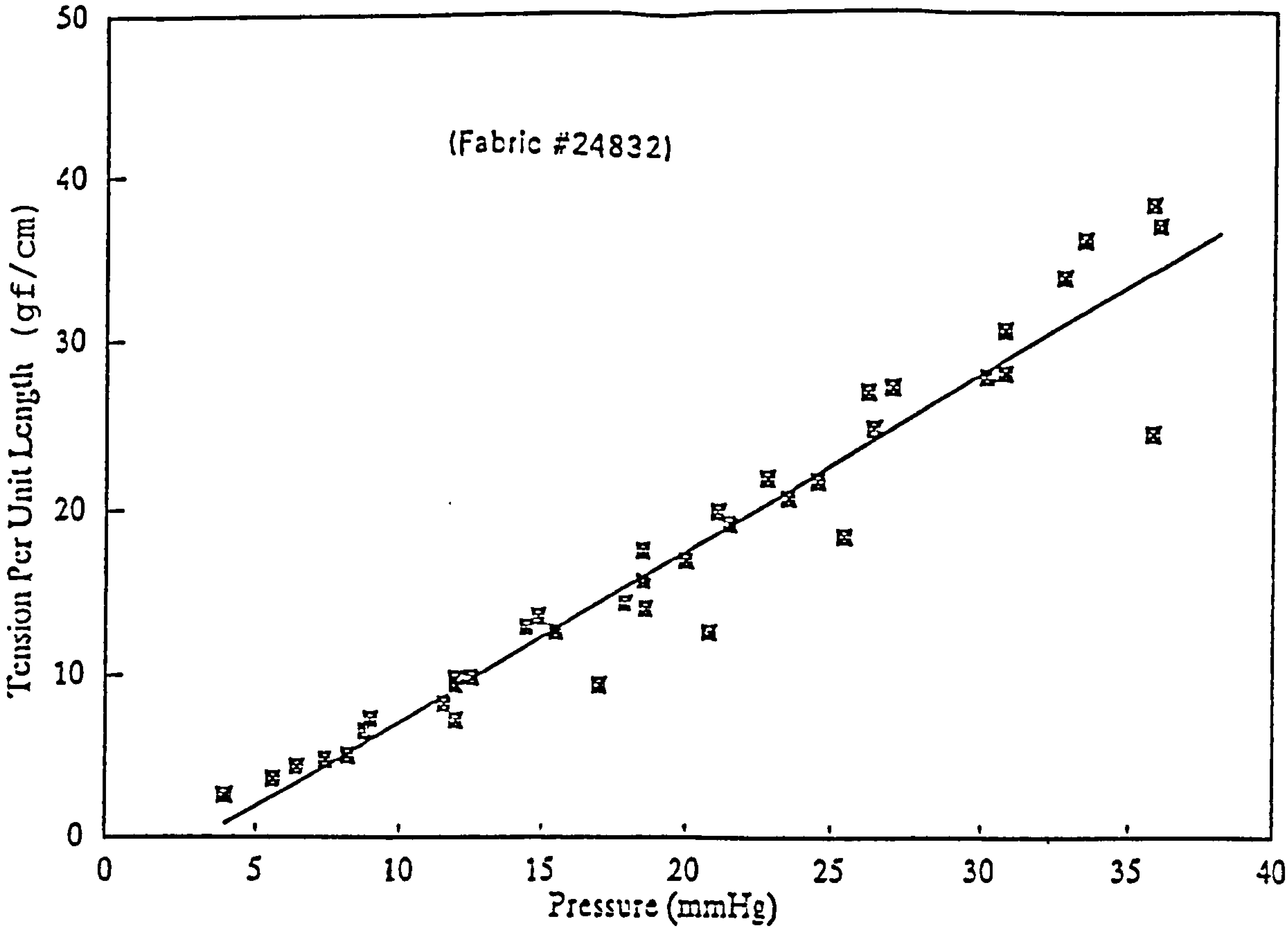


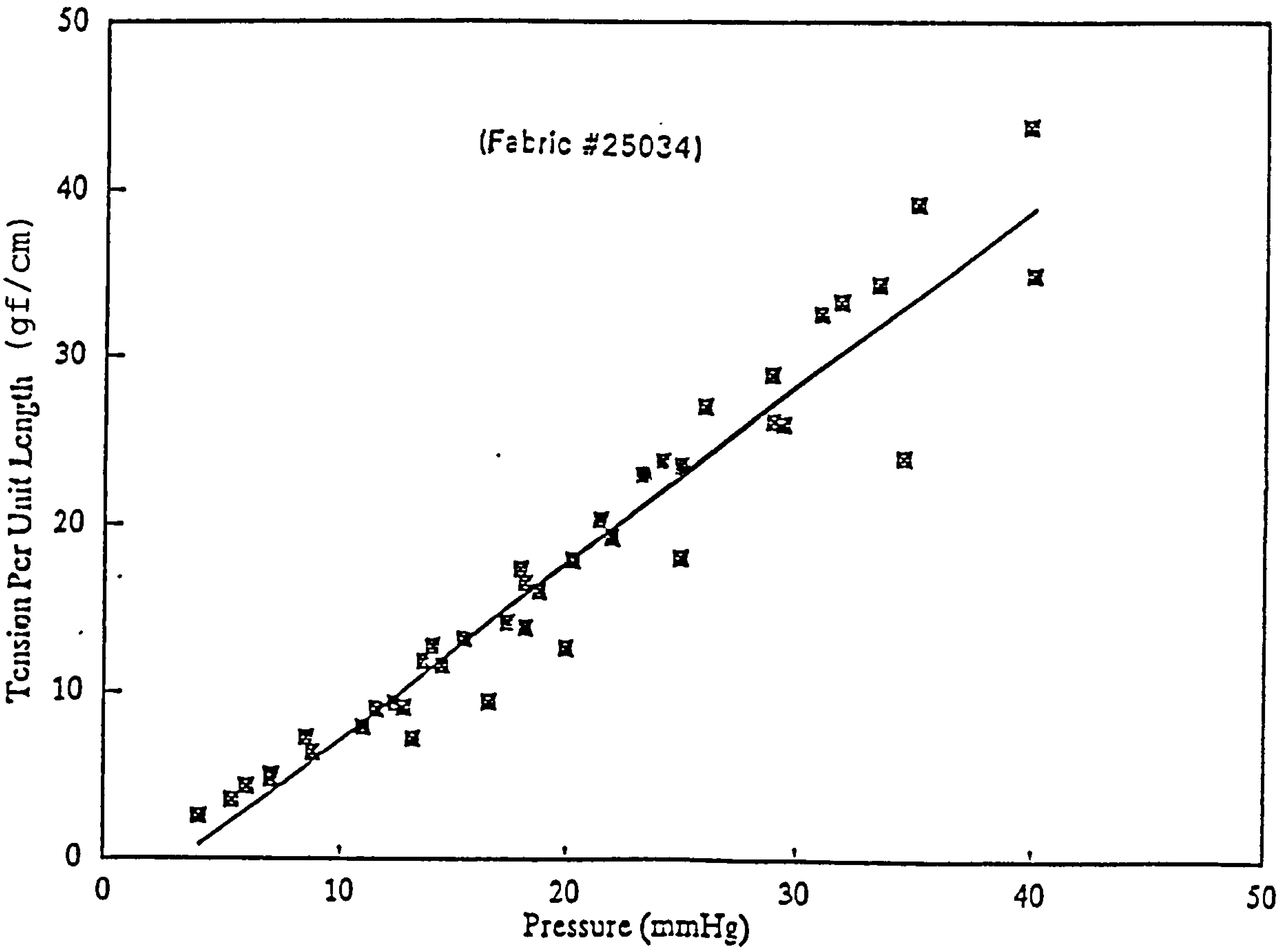
Graph 3.10 The Change of Pressure (mmHg) Vs 1/Circumference (1/cm) of the Tube Models





Graph 3.11 The Change of Tension Per Unit Circumferential Length (g force/cm) Vs Interface Pressure (mmHg) Measured from the Tube Models





Graph 3.12 The Change of Tension Per Unit Circumferential Length (g force/cm) Vs Interface Pressure (mmHg) Focusing within the Range 5-40 mmHg

As can be seen from the graphs No. 3.11 and 3.12, this gives a straight line but not through the origin as would be expected by theory. There appears to be a residual or contact pressure even when there is zero tension in the fabric, and this contact pressure varies with the tube circumference.

Regression analysis of the experimental results (showed at Graph 3.12) gives the equation below:

$$T / C = A + B P$$

or $$T = (A + BP)\ C$$

where T = Fabric Tension

C = Circumference of tube (or limb)

P = Pressure

A = a constant (the intercept indicates the amount of contact pressure)

B = the slope of the Pressure vs Fabric Tension graph

This empirical equation derived from the experimental results is similar to what one would expect from the theory, the main difference being that the constant A would be zero from the theory.

Based on the Graph 3.12, as the values of A and B derived from the equation of both fabric #28432 and #25034 are almost the same, it is expected that the same constant A and B can be used for the calculation.

	'A' Constant	'B' Constant
Fabric #28432	-3.29759	1.044743
Fabric #25034	-3.39553	1.058186
Mean Value	-3.35	1.05

3.4.2 Comparison between the Interface Pressure Measured from the Experimental Tube Model and on Human Body

In order to compare the interface pressure produced at the same curve surface between the tube model and on human body, the possible pressure produced on the tube model of the same circumferential measurement as the human limbs were derived from the experimental data (refer to Table 3.3 and Graph 3.1) on the tube models. The pressure worked out from the Graph 3.1 are presented at Table 3.10.

Based on the data at Table 3.10, the change of pressure on tube models vs different reduced percentage of pressure garment at various circumference same to the size of human upper and lower limbs were indicated at the Graph 3.13 and 3.14.

Referring to the pressure recorded from the upper and lower limbs of the human body at section 3.2.3 (see Appendix 7), the change of pressure vs different reduced percentage of garment at various circumference of the lower and upper limbs were indicated at the Graph 3.15 and 3.16 respectively.

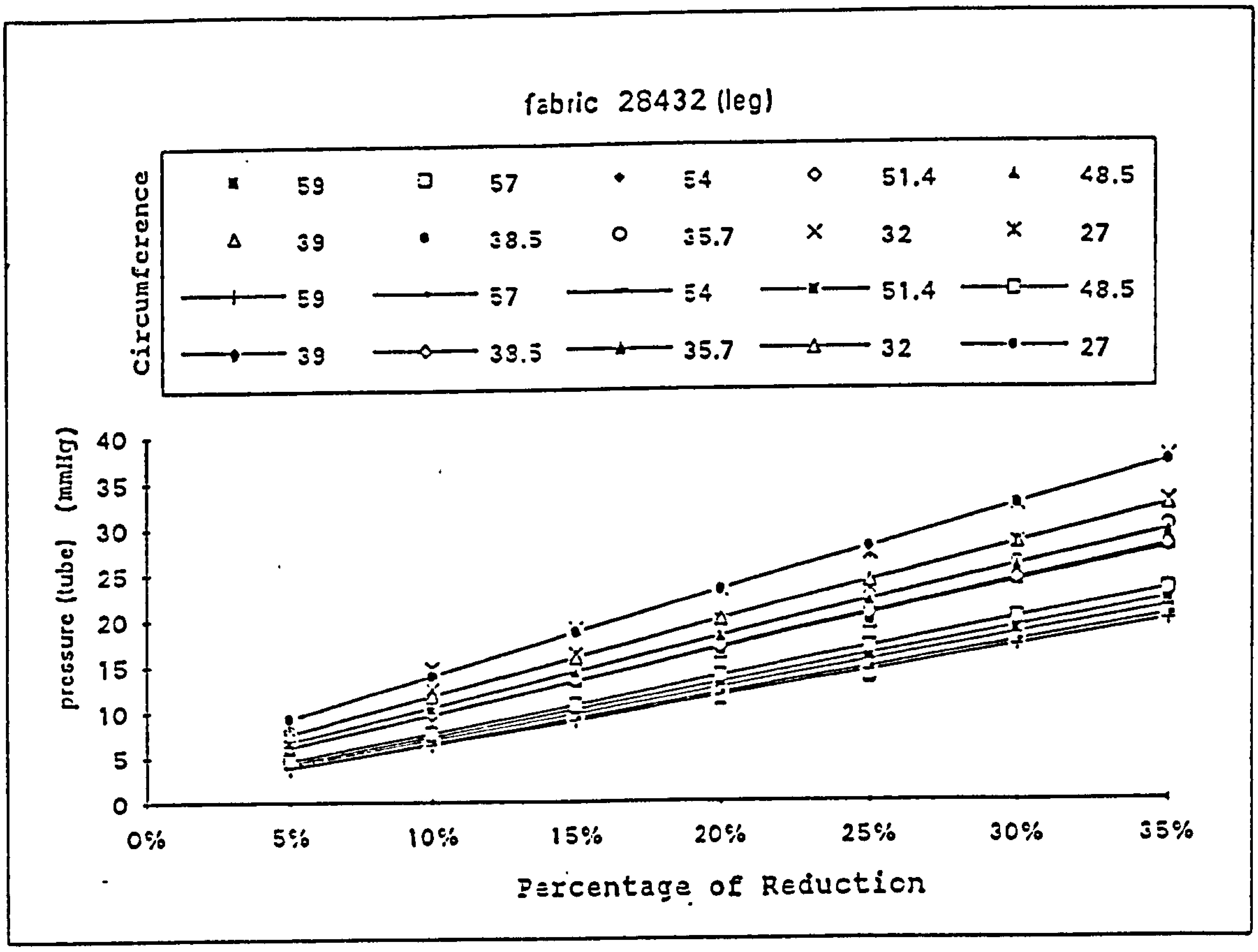
Fabric #28432

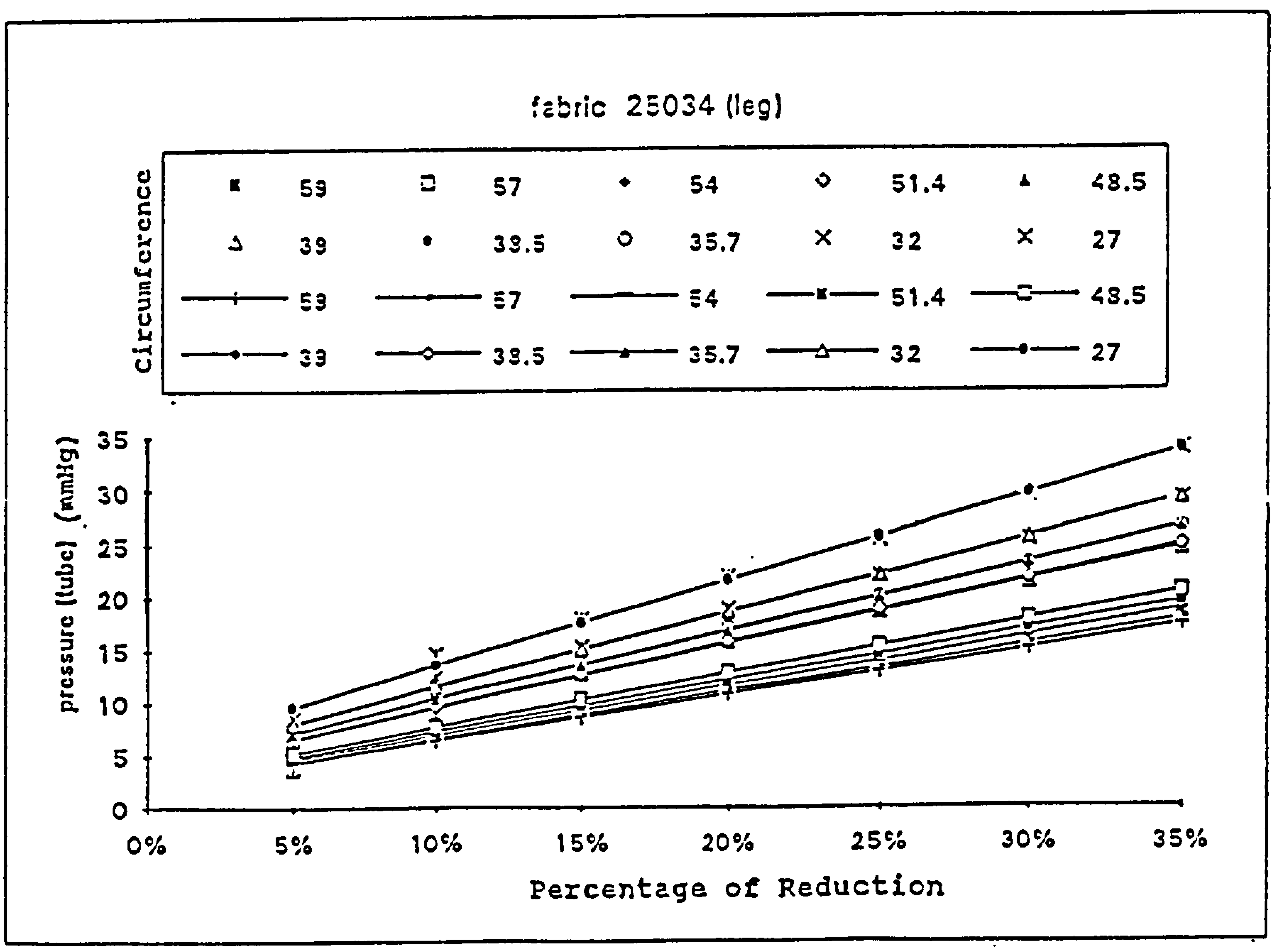
Circumference (cm)	5%	10%	15%	20%	25%	30%	35%
			Percentage of Reduction (%)				
59	3.5	6.9	9.3	11.2	13.5	17.4	20
57	3.7	7.2	9.6	11.5	13.9	17.9	20.6
54	3.9	7.6	10.1	12.1	14.6	18.7	21.5
51.4	4.2	7.9	10.5	12.7	15.2	19.4	22.3
48.5	4.4	8.4	11.1	13.4	16.0	20.3	23.4
39	5.7	10.4	13.5	16.4	20.0	24.1	27.9
38.5	5.8	10.5	13.7	16.6	19.7	24.4	28.2
35.7	6.3	11.3	14.7	17.8	21.1	25.9	30.0
32	7.2	12.6	16.2	19.7	23.2	28.2	32.7
27	8.8	14.8	18.9	23.1	27.0	32.3	37.5
32	7.2	12.6	16.2	19.7	23.2	28.2	32.7
30.6	7.6	13.1	16.9	20.6	24.2	29.3	33.9
29	8.1	13.8	17.7	21.6	25.3	30.5	35.4
27.2	8.7	14.7	18.8	22.9	26.8	32.1	37.3
26.2	9.1	15.2	19.4	23.8	27.7	33.1	38.4
23.8	10.1	16.7	21.2	26.0	30.2	35.7	41.5
20.6	12.0	19.2	24.2	29.7	34.4	40.1	46.7
18.7	13.4	21.1	26.4	32.5	37.4	43.3	50.4

Fabric #25034

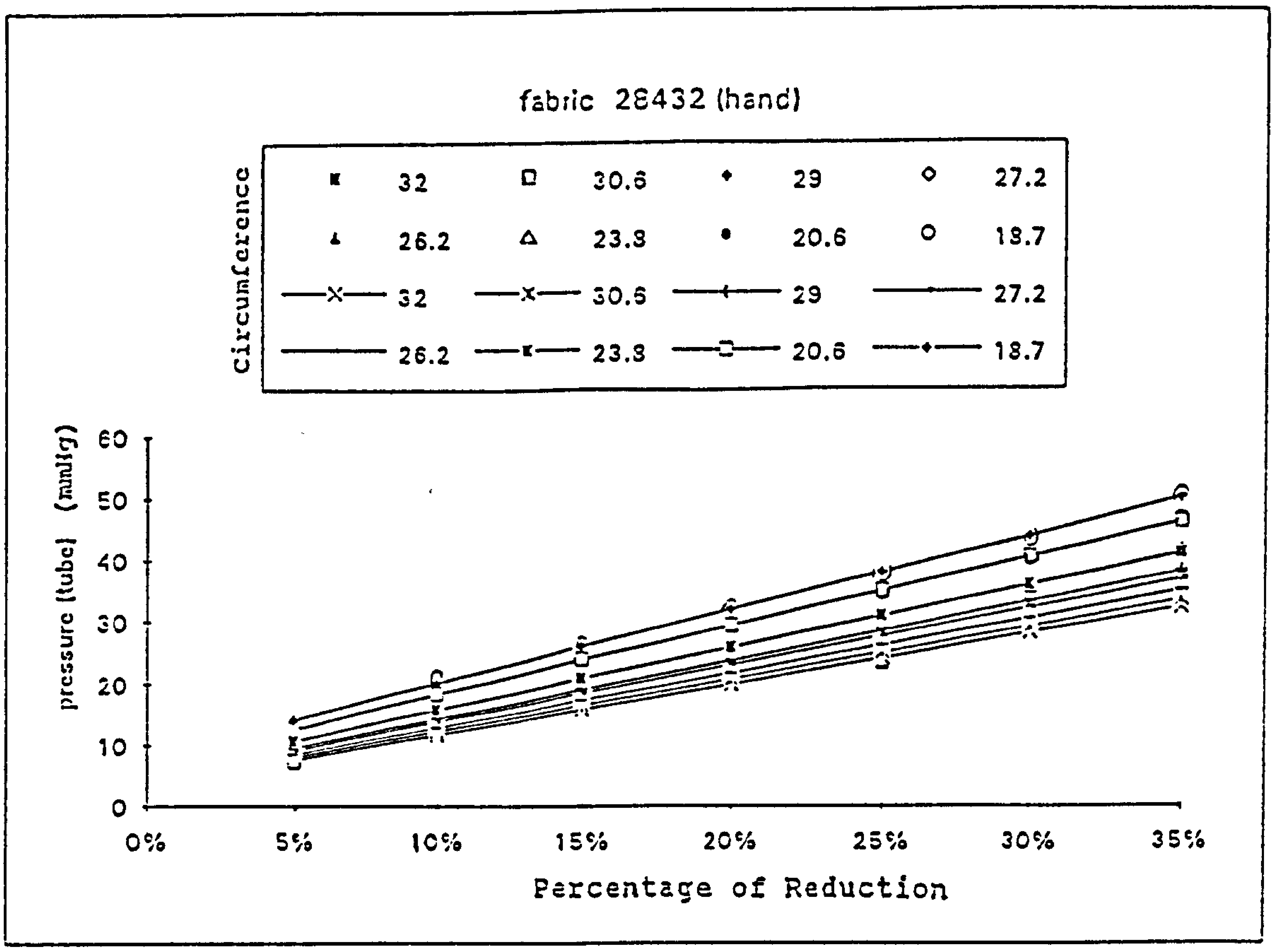
Circumference (cm)	5%	10%	15%	20%	25%	30%	35%
			Percentage of Reduction (%)				
59	3.6	7.1	8.8	11.0	13.1	15.1	17.1
57	3.7	7.3	9.0	11.3	13.5	15.5	17.6
54	3.9	7.7	9.5	11.9	14.2	16.3	18.5
51.4	4.2	8.1	9.9	12.4	14.8	17.0	19.3
48.5	4.4	8.5	10.5	13.1	15.5	17.8	20.3
39	5.7	10.4	12.8	15.9	18.7	21.5	24.5
38.5	5.8	10.6	13.0	16.1	18.9	21.7	24.8
35.7	6.3	11.3	13.9	17.2	20.1	23.2	26.5
32	7.1	12.5	15.4	18.9	22.1	25.4	29.2
27	8.6	14.7	17.9	22.0	25.5	29.4	33.8
32	7.1	12.5	15.4	18.9	22.1	25.4	29.2
30.6	7.5	13.1	16.0	19.7	22.9	26.4	30.3
29	7.9	13.7	16.8	20.7	24.0	27.7	31.8
27.2	8.5	14.6	17.8	21.9	25.3	29.3	33.6
26.2	8.9	15.1	18.5	22.6	26.1	30.2	34.7
23.8	9.9	16.5	20.2	24.6	28.4	32.8	37.7
20.6	11.7	18.9	23.0	28.0	32.1	37.1	42.8
18.7	13.0	20.7	25.1	30.6	34.8	40.3	46.5

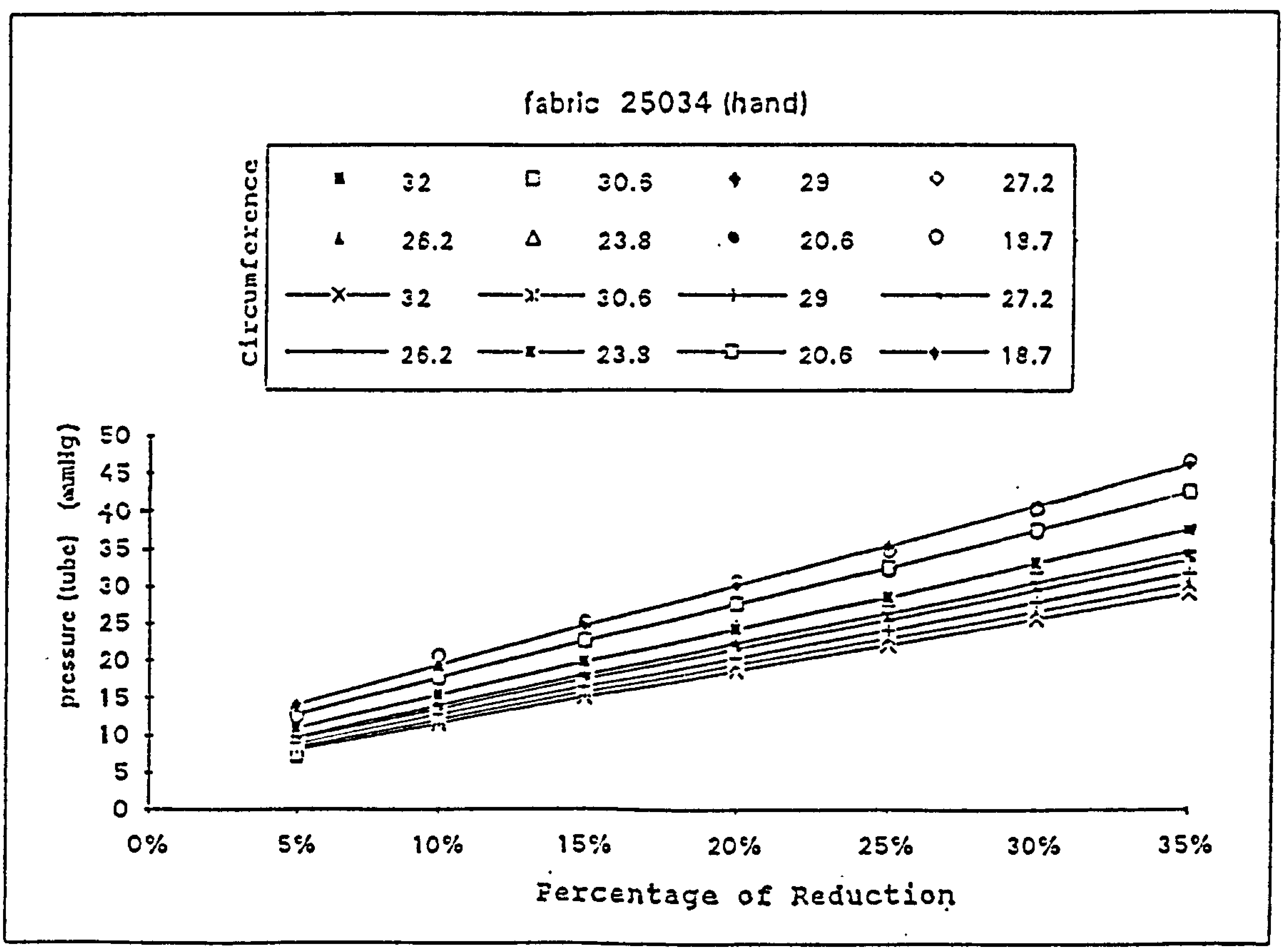
Table 3.10 Possible Pressure (mmHg) Produced on the Tube Model when Its Size is Same to the Human Limbs



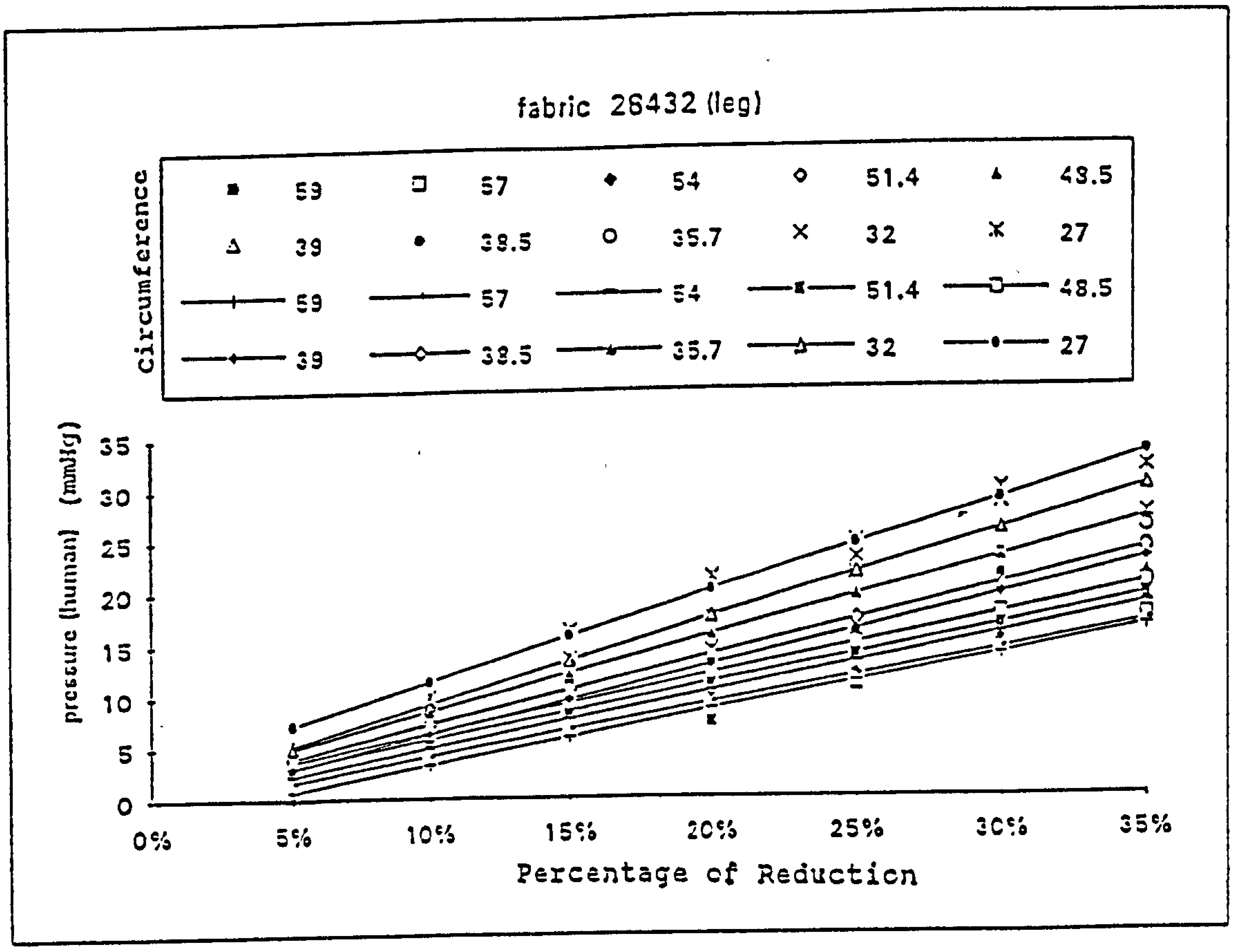


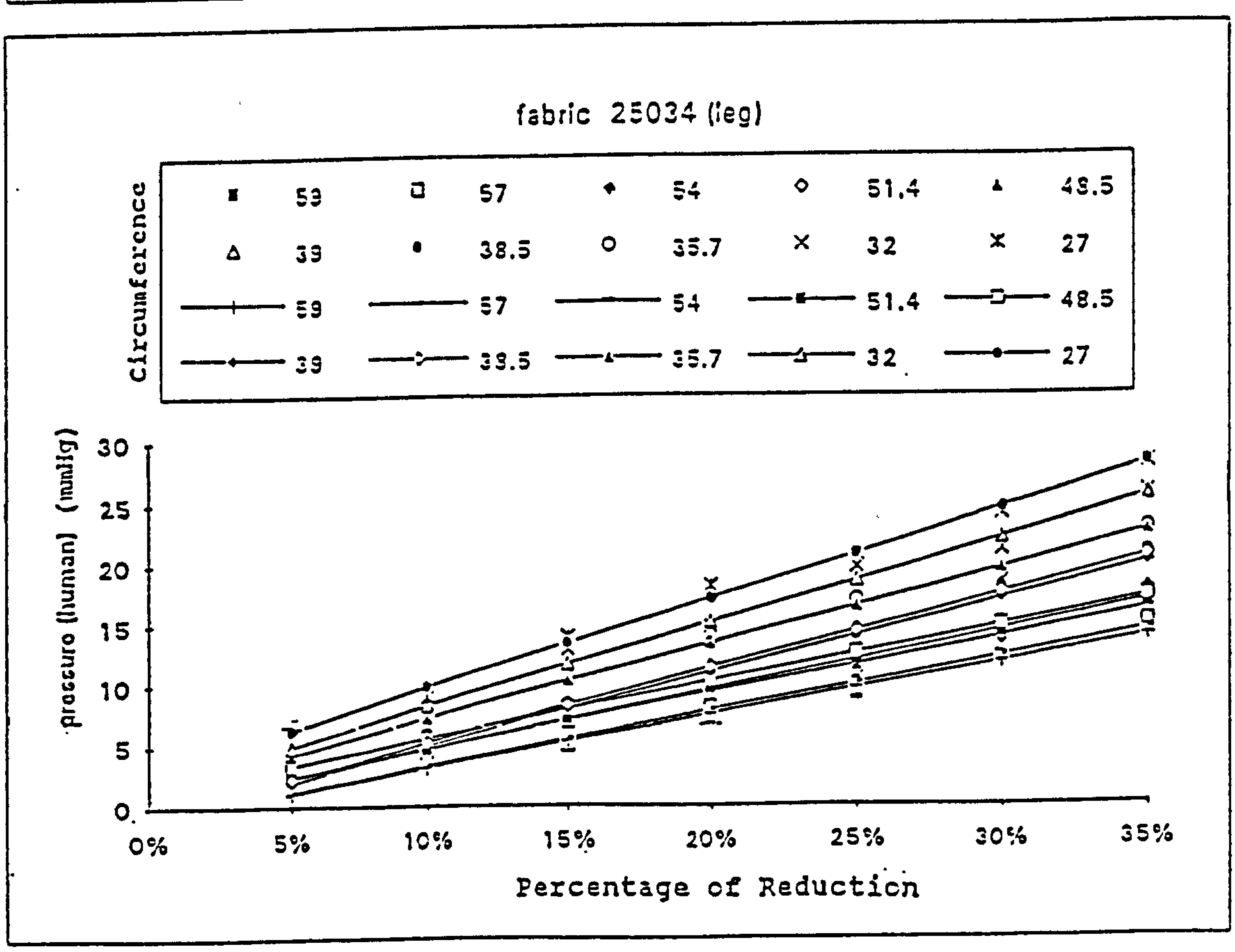
Graph 3.13 The Change of Pressure (mmHg) on Tube Models Vs Different Reduced Percentage of Pressure Garment at Various Circumference (cm) same to the Size of Human Lower Limbs



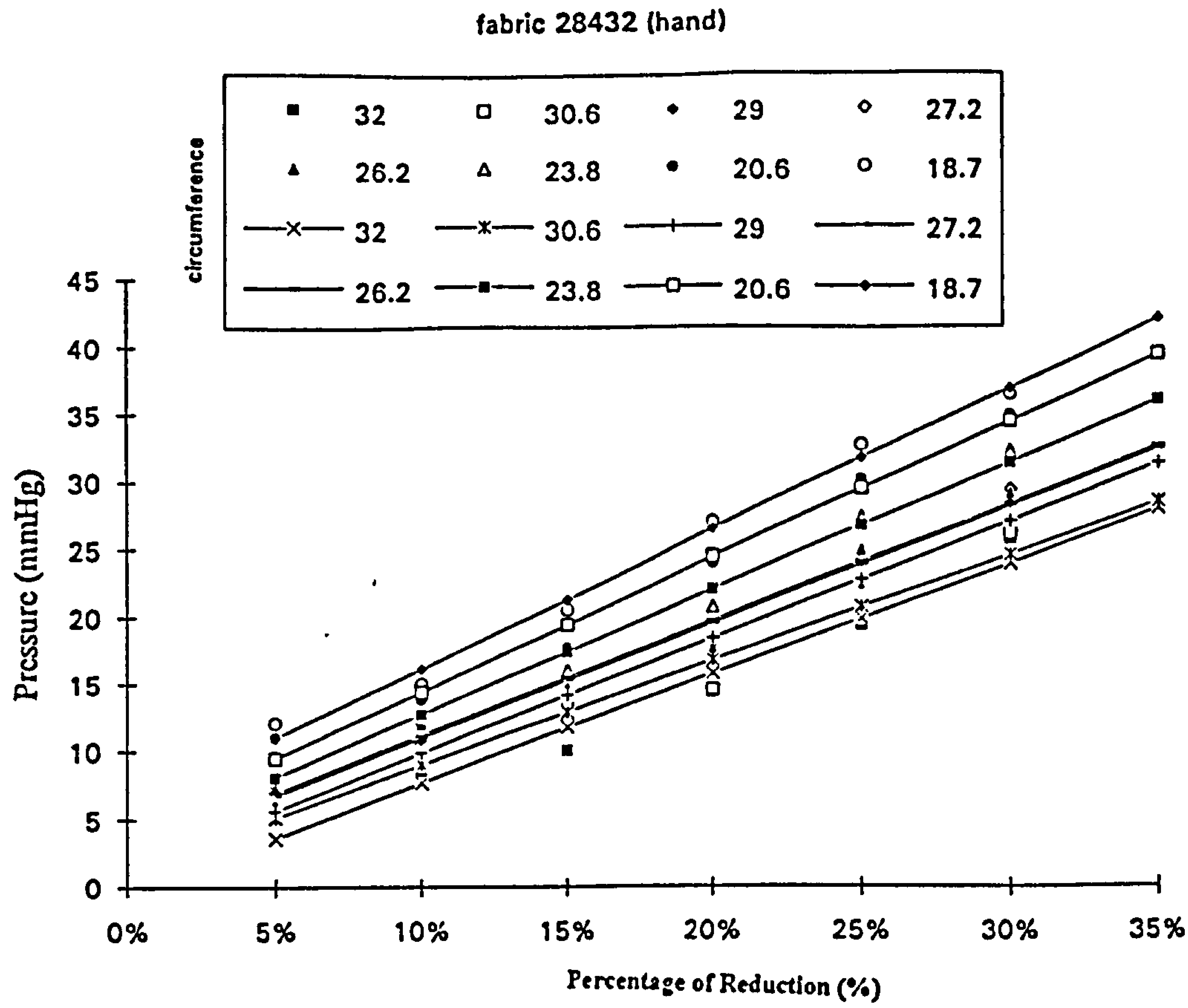


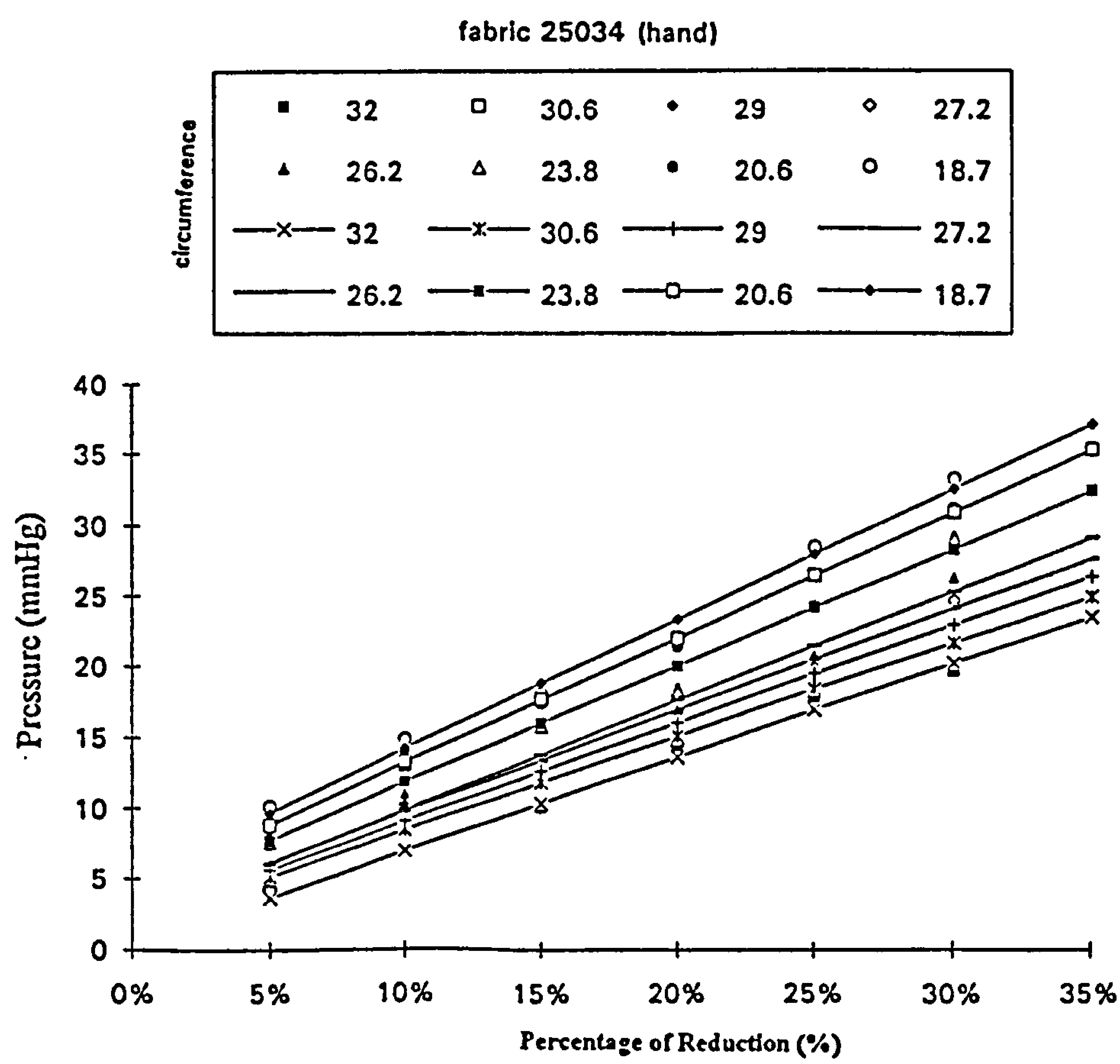
Graph 3.14 The Change of Pressure (mmHg) on Tube Models Vs Different Reduced Percentage of Pressure Garment at Various Circumference (cm) same to the Size of Human Upper Limbs





Graph 3.15 The Change of Pressure (mmHg) on Human Vs Different Reduced Percentage of Pressure Garment at Various Circumference (cm) of the Lower Limbs





Graph 3.16 The Change of Pressure (mmHg) on Human Vs Different Reduced Percentage of Pressure Garment at Various Circumference (cm) of the Upper Limbs

By comparing the slope of these two sets of graphs (compare Graph 3.13 to Graph 3.15; and Graph 3.14 to Graph 3.16), the difference of the pressure at various circumference between the human and the tube model can be found. Table 3.11 shows the slope of the tube model graphs (Graphs 3.13 and 3.14) ; the slope of human graphs (Graphs 3.15 and 3.16); and also the ratio of the slope of these two sets of graphs.

For the lower limbs of circumference range from 27cm to 59cm, the range of the slope ratio was from 0.91 to 1, while the upper limbs (size 18.7cm - 32cm in circumference) was range from 0.85 to 0.97 in ratio. It was noted that the ratio between the slope of human to the slope of the tube model graphs was quite different between the lower and upper limbs, but it was very similar between the two fabrics tested.

As shown in Graph 3.17, the slope ratio of lower limbs was in general 0.95, this indicates that the average pressure measured on the lower limbs of human body is 5% lower than those measured from the tube model. But the average of the slope ratio of upper limbs was only 0.9 (see Graph 3.18), this meant the average pressure measured on the upper limbs of human body was much lower (around 10%) than those measured from the tube model.

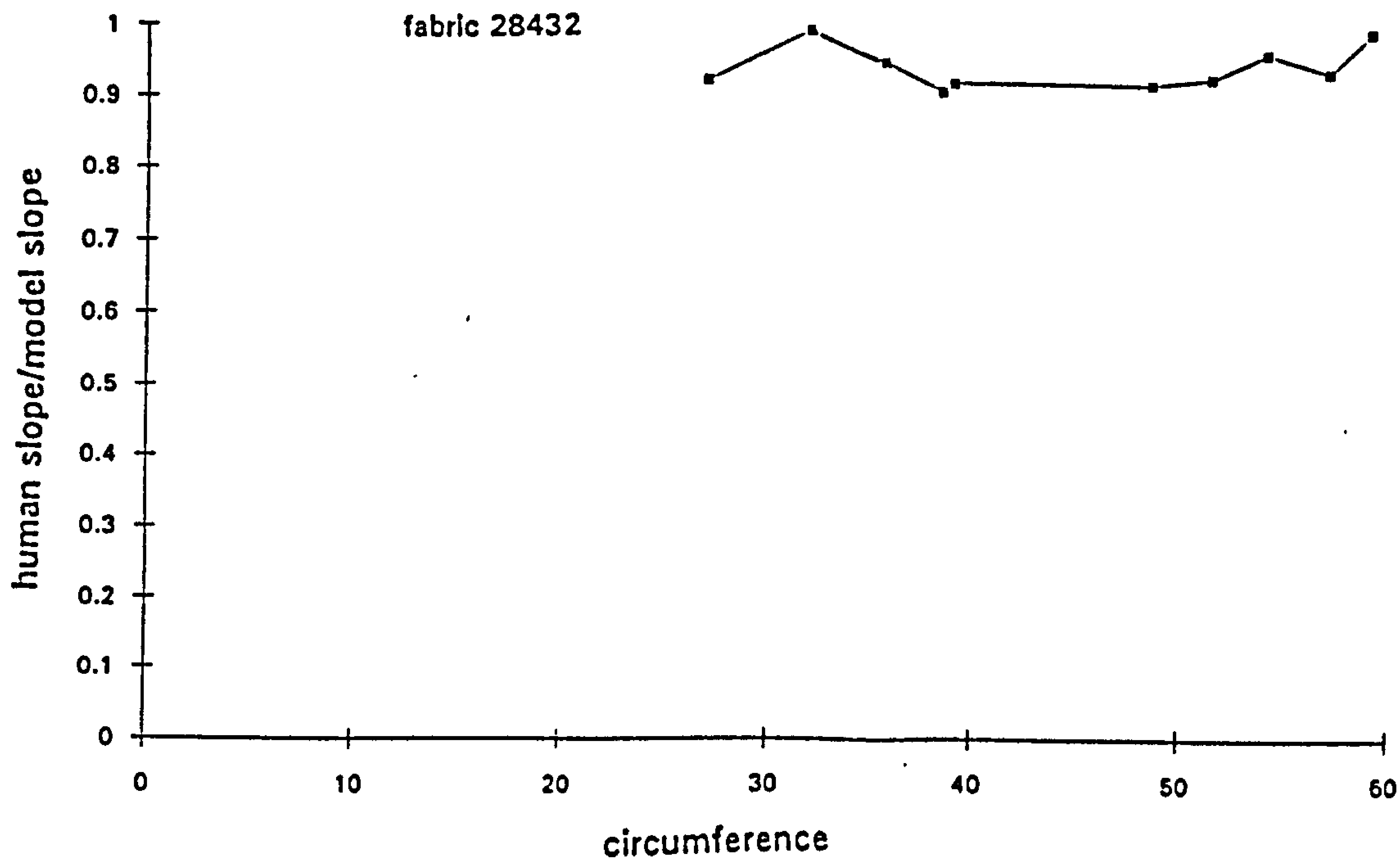
Fabric #28432

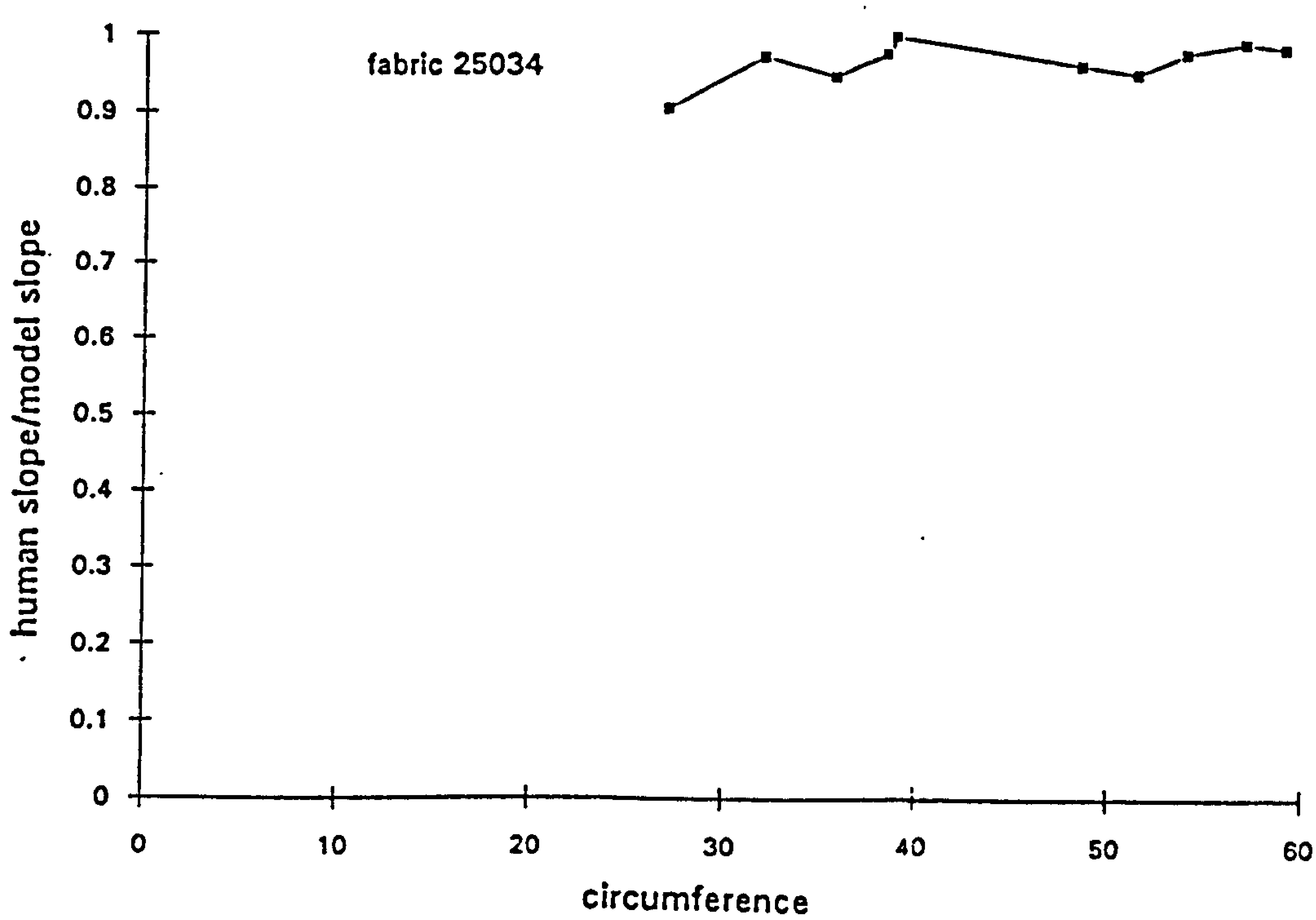
Cirumference (cm)	Slope of Human Curves	Slope of Tube Model Curves	Ratio of Human Curves & Model Curves
59	52.3	53.1	0.985
57	50.7	54.4	0.931
54	54.2	56.7	0.957
51.4	54.2	58.7	0.923
48.5	56.1	61.3	0.915
39	66.2	72	0.92
38.5	66.0	72.7	0.909
35.7	73.1	76.8	0.957
32	82.6	83.2	0.994
27	86.6	94	0.921
32	80.7	83.2	0.971
30.6	77.5	85.9	0.902
29	85.3	89.3	0.955
27.2	85.1	93.5	0.91
26.2	85	96	0.885
23.8	92.5	102.9	0.899
20.6	99.3	114	0.871
18.7	103	122	0.845

Fabric #25034

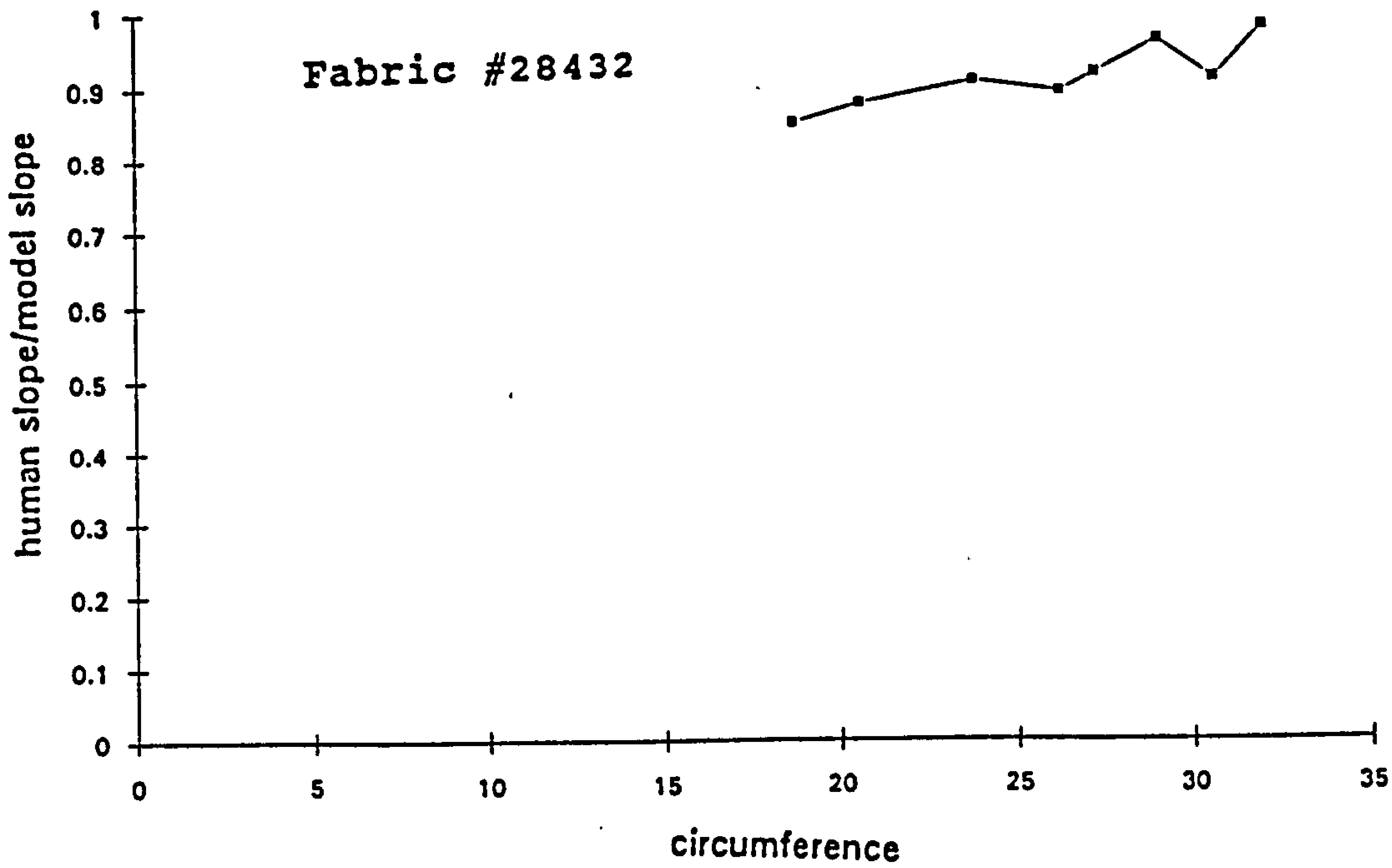
Cirumference (cm)	Slope of Human Curves	Slope of Tube Model Curves	Ratio of Human Curves & Model Curves
59	42.8	43.6	0.983
57	44.3	44.8	0.990
54	45.6	46.7	0.976
51.4	46.1	48.6	0.949
48.5	48.9	50.9	0.961
39	60.2	60.4	0.997
38.5	59.5	61.0	0.976
35.7	61.2	64.7	0.946
32	66.3	70.5	0.971
27	72.9	80.5	0.905
32	66.3	70.5	0.94
30.6	66.1	73.0	0.904
29	69.3	76.1	0.91
27.2	71.8	80.0	0.897
26.2	77.3	82.4	0.938
23.8	82.6	88.8	0.93
20.6	88.6	99.2	0.893
18.7	91.9	106.9	0.86

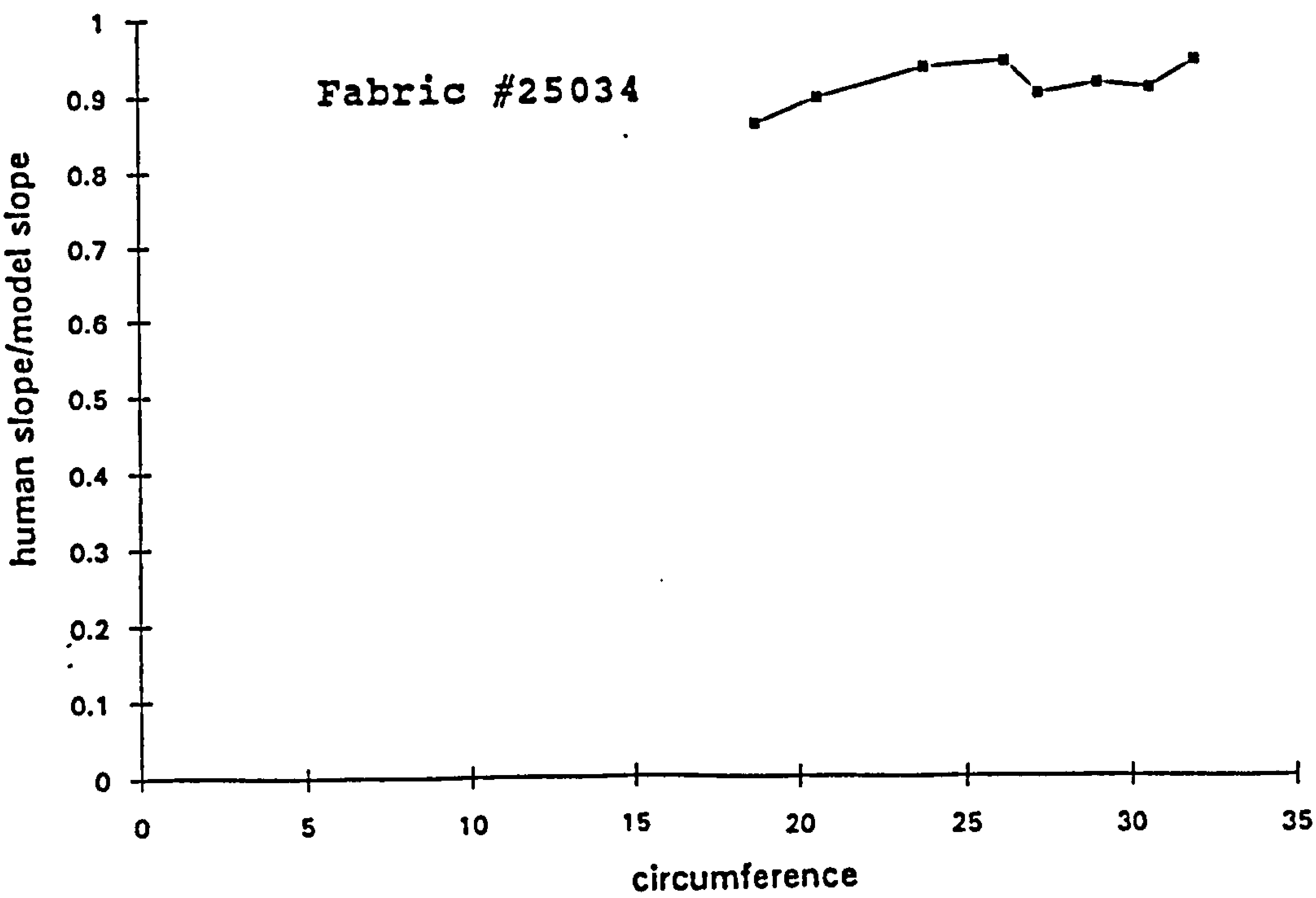
Table 3.11 The Slope of Human Graphs and Tube Model Graphs





Graph 3.17 The Ratio Between the Slope of Human Graphs to the Slope of the Tube Model Graphs at Various Circumference (cm) of Lower Limbs





Graph 3.18 The Ratio Between the Slope of Human Graphs to the Slope of the Tube Model Graphs at Various Circumference (cm) of Upper Limbs

The difference of the pressure between the human and tube model may be due to experimental errors. As the Oxford Monitor MKII pressure transducer is not of very high accuracy (± 3mmHg), this tolerance range may cause some pressure variations. There is also difficulty in recording measurement of limbs very accurately, because the shape of limbs may change during measuring; the amount of tension applied on measuring tape determines the size of the limbs. The most probable cause of the pressure difference is due to the change of the size of the limbs upon the compression of pressure garments. When a high compressive garment is applied on limbs, the size of limbs certainly will decrease by a certain percentage, this means the stretch percentage of the pressure garment as well as the size of interface curve surface both become smaller.

Consider the case of a lower limb with initial circumference of 50cm which with the pressure garment in place contracts by 2 %, that means the new circumference of the limb will be 49cm. If the garment was made with a reduced percentage of 30%, then the relaxed fabric circumference will be : 50 cm x (70/100) = 35 cm.

The fabric extension will then be 49cm - 35cm = 14cm instead of 50cm - 35cm = 15cm; that means the stretch percentage of fabric will become 40% (14/49 x 100% = 40%) instead of 42.9% (15/50 x 100% = 42.9%).

If the size of a limb is not affected by garment compression, the stretch percentage of the garment is 42.9%, the possible tension force induced on the curve surface will be 940 gf for the fabric #28432 (referring to the load-extension curve of the fabric #28432 at Graph 3.7). However, if the size of a limb contracts by 2% and the stretch of fabric is changed to 40%, the fabric tension will thus become 880 gm. instead of 940 gm. (based on the data at Graph 3.7).

Based on the equation that $T/C = A + BP$,

when $T = 940\text{gm}$; $C = 50\text{cm}$; $(A = -3.35;\ B = 1.05)$

then $P = (940/50 + 3.35) / 1.05 = 18\text{mmHg}$

If $T = 880$ gm; $C = 49\text{cm}$;

then $P = (880/49 + 3.35) / 1.05 = 17\text{mmHg}$

Thus, the pressure will decrease by approximate

$(18\text{mmHg} - 17\text{mmHg}) / 18\text{mmHg} \times 100\% = 4\%$

Consider another case of an upper limb with an initial circumference of 20cm which with the pressure garment in place contracts by 5%, that means the new circumference of the limb will be 19cm. If the garment was made of fabric #28432 and again with a reduced percentage of 30%, then the relaxed fabric circumference will be : $20\text{cm} \times (70/100) = 14\text{cm}$

The fabric extension will then be 19cm - 14cm = 5cm instead of 20cm- 14cm = 6cm, and the stretch percentage of the fabric will become 35.7% instead of 42.9%.

If the size of the limb remains 20cm after the pressure garment is put in place, the fabric stretch will be 42.9% and the fabric tension applied to the curve surface will be 940 gm force (based on the load-extension curve of fabric #28432). The pressure worked out from the equation (T/C = A + BP) will then become (940/20 + 3.35) / 1.05 = 48mmHg.

But if the new circumference of the limb is 19cm and the fabric stretch is changed to 35.7%, the fabric tension will become 795gm force (based on Graph 3.7). The pressure applied on the surface of the limb will then be (795/19 + 3.35) / 1.05 = 43mmHg.

In this case, the pressure will decrease by approximately (48mmHg - 43mmHg) / 48 mmHg x 100% = 10%.

The above two cases explain why percentage of pressure loss is higher when there is greater change of the size of the limbs upon the compression of pressure garments.

During the study at section 3.2.3, it was observed that both upper and lower limbs change their size upon the compression of pressure garments. In general, the lower limbs were found to reduce in size by around 1-2%, and the upper limbs by around 3-4% in circumference measurement. Obviously the size of a limb becomes smaller when the pressure garment is made with a higher percentage of reduction.

Such differences between the lower and upper limbs may be due to anatomical structure, or the experimental errors. If the same amount of variations occured to lower and upper limbs during the experiment, certainly the smaller the circumference, the percentage of variation would be higher. Another most probable cause of such differences is due to the posture of the human subject when recording the pressure. As the hands hang down in a natural position, the muscle of upper limbs is more flaccid and can be compressed by pressure garment more easily, but the muscle of lower limbs became firmer at a standing position, therefore the size of lower limbs was less affected by the garment compression.

As the pressure measured on the human body was slightly lower than those obtained on the experimental tube model, a correction of the Pressure value is required before the application of the equation as explained at section 3.4.1.

Consider the equation : $T = (A + B\,P_{tube})\,C$

If $P_{human} = R\,P_{tube}$

the equation will then become : $T = (A + B\,P_{human} / R)\,C$

where R = Ratio of the slope of pressure curves between human and tube model

P_{tube} = Pressure recorded from tube models

P_{human} = Pressure recorded from human body

C = Circumference of limbs

T = Fabric Tension

A = a constant (the intercept indicates the amount of contact pressure)

B = the slope of the Pressure vs Fabric Tension graph

Since the ratio of the slope of pressure graphs between human and tube model is different between the lower and upper limbs, the R on the above equation is not a constant for every part of the human body. If the equation is applied for lower limbs, the R will be 0.95, but in the case of upper limbs, it will becomes 0.9.

3.4.3 Development of Drafting Rules to Make Pressure Garments

Based on the formula derived from the previous section 3.4.2 , the prediction of the amount of fabric tension required for a particular size of limb and a particular level of skin-garment interface pressure can be achieved.

Table 3.13 and 3.14 indicate the amount of fabric tension (gm. force) required for various sizes (circumference cm.) of lower and upper limbs at various level (mmHg) of skin-garment interface pressure.

	Skin-Garment Interface Pressure					
Circumference of Limbs	10 mmHg	15 mmHg	20 mmHg	25 mmHg	30 mmHg	35 mmHg
20 cm	154	265	375	486	596	707
25 cm	193	331	469	607	745	883
30 cm	231	397	563	728	894	1060
35 cm	270	463	656	850	1043	1236
40 cm	308	529	750	971	1192	1413
45 cm	347	595	844	1093	1341	1590
50 cm	385	661	938	1214	1490	1767
55 cm	424	728	1032	1335	1639	1943
60 cm	462	794	1125	1457	1788	2120

Table 3.13 Table of Fabric Tension (gf) required on Different Sizes (cm) of Lower Limbs for Various Skin-Garment Interface Pressure (mmHg)

Circumference of Limbs	Skin-Garment Interface Pressure 10 mmHg	15 mmHg	20 mmHg	25 mmHg	30 mmHg	35 mmHg
15 cm	128	212	300	387	475	562
20 cm	166	283	400	516	633	750
25 cm	208	354	500	645	791	937
30 cm	250	425	600	775	950	1125
35 cm	291	495	699	904	1108	1312
40 cm	333	566	799	1033	1266	1499

Table 3.14 Table of Fabric Tension (gf) required on Different Sizes (cm) of Upper Limbs for Various Skin-Garment Interface Pressure (mmHg)

Based on the data as shown at Table 3.13 and 3.14, it is possible to estimate the amount of fabric stretch (stretch %) required for such fabric compression (gf) by co-relating to the load-extension curves of the two elastic fabrics (refer to Graph 3.7).

As the pressure garment is made by reducing a certain percentage from the acutal size of human body, for the convenience of the therapists to use in actual practice, the stretch percentage of fabric as shown at Table 3.13 and 3.14 was converted to the percentage of reduction of pressure garment (as shown at Table 3.15 and 3.16).

Fabric #28432

Circumference of Limbs	Skin-Garment Interface Pressure					
	10 mmHg	15 mmHg	20 mmHg	25 mmHg	30 mmHg	35 mmHg
20 cm	5	9.5	14.2	20	24.8	31.2
25 cm	6.8	12.5	18.8	25.4	33.2	40.1
30 cm	8.2	15.8	23.4	32.2	40.8	50
35 cm	9.5	18.6	27.8	38.5	49	59
40 cm	11.5	21.8	33.3	45.2	57.2	68.6
45 cm	13.2	24.8	38.2	51.6	65	78.2
50 cm	14	28.4	42.6	58	72.8	87
55 cm	17	32.2	48.2	64.5	81	96.5
60 cm	18.5	35.6	52.5	70.8	88.8	104

Fabric #25034

Circumference of Limbs	Skin-Garment Interface Pressure					
	10 mmHg	15 mmHg	20 mmHg	25 mmHg	30 mmHg	35 mmHg
20 cm	5	10	15.5	21.2	27	33.6
25 cm	6.8	13.2	20	27.5	35.7	45.2
30 cm	9.5	16.6	25.2	34.8	46.2	57
35 cm	10.4	19.8	30	43	55.6	68.5
40 cm	12	23.5	35.8	51.3	66.2	80.5
45 cm	14	27	42.6	59.5	75.5	91.5
50 cm	15	30.5	49	67.2	85.6	103
55 cm	18	34.8	54.8	75.2	95	114
60 cm	20	39.2	60.5	83	105	122

Table 3.15 The Percentage of Extension (Stretch %) of Pressure Garment for Different Size (cm) of Lower Limbs at Different Pressure (mmHg) Ranges

Fabric *28432

Skin-Garment Interface Pressure

Circumference of Limbs	10 mmHg	15 mmHg	20 mmHg	25 mmHg	30 mmHg	35 mmHg
15 cm	4.5	7.6	11	14	18.9	23.4
20 cm	6	10.7	16	21	26.6	33.3
25 cm	7.2	13.3	20.5	27.7	35.5	42.6
30 cm	9	17	24.9	34.6	43.8	52.5
35 cm	10.7	20.5	31.1	41.5	52.3	63.2
40 cm	12.5	23.4	35.7	48.2	60.7	73

Fabric *25034

Skin-Garment Interface Pressure

Circumference of Limbs	10 mmHg	15 mmHg	20 mmHg	25 mmHg	30 mmHg	35 mmHg
15 cm	4.5	7.9	11.6	15	20.1	25.2
20 cm	6	11.2	16.8	22.4	28.9	35.6
25 cm	7.6	14.2	22	29.8	39.1	49
30 cm	9.3	18.2	27.1	38	49.8	60.5
35 cm	11.2	22	33.2	45.6	60.2	73.5
40 cm	13.2	25.2	39.3	54.8	70.6	86

Table 3.16 The Percentage of Extension (Stretch %) of Pressure Garment for Different Sizes (cm) of Upper Limbs at Different Pressure (mmHg) Range

The change of stretch percentage of fabric into reduced percentage of garment can be done by referring to the Graph 3.13 which indicates the relationship between stretch % of fabric and reduced % of garment; or the convertion can be made by calculation based on the equation : stretch % = reduced % / (100 - reduced %) . See Table 3.17 and 3.18 for the result.

Fabric #28432

Skin-Garment Interface Pressure

Circumference of Limbs	10 mmHg	15 mmHg	20 mmHg	25 mmHg	30 mmHg	35 mmHg
20 cm	4.8	8.7	12.4	16.7	19.9	23.8
25 cm	6.4	11.1	15.8	20.3	24.9	28.6
30 cm	7.6	13.6	19	24.4	29	33.3
35 cm	8.7	15.7	21.8	27.8	32.9	37.1
40 cm	10.3	17.9	25	31.1	36.4	40.7
45 cm	11.7	19.9	27.6	34	39.4	43.9
50 cm	12.3	22.1	29.9	36.7	42.1	46.5
55 cm	14.5	24.4	32.5	39.2	44.8	49
60 cm	15.6	26.3	34.4	41.5	47	51

Fabric #25034

Skin-Garment Interface Pressure

Circumference of Limbs	10 mmHg	15 mmHg	20 mmHg	25 mmHg	30 mmHg	35 mmHg
20 cm	4.8	9.1	13.4	17.5	21.3	25.2
25 cm	6.4	11.7	16.7	21.6	26.3	31.1
30 cm	8.7	14.2	20.1	25.8	31.6	36.3
35 cm	9.4	16.5	23.1	30.1	35.7	40.6
40 cm	10.7	19	26.4	33.9	39.8	44.6
45 cm	12.3	21.3	29.9	37.3	43	47.8
50 cm	13	23.4	32.9	40.2	46.1	50.7
55 cm	15.3	25.8	35.4	42.9	48.7	53.3
60 cm	16.7	28.2	37.7	45.4	51.2	55

Table 3.17 The Percentage of Reduction (Reduced %) of Pressure Garment for Different Sizes (cm) of Lower Limbs at Different Pressure (mmHg) Ranges

Fabric #28432

Skin-Garment Interface Pressure

Circumference of Limbs	10 mmHg	15 mmHg	20 mmHg	25 mmHg	30 mmHg	35 mmHg
15 cm	4.3	7.1	9.9	12.3	15.9	19
20 cm	5.7	9.7	13.8	17.4	21	25
25 cm	6.7	11.7	17	21.7	26.2	29.9
30 cm	8.3	14.5	19.9	25.7	30.6	34.4
35 cm	9.7	17.	23.7	29.3	34.3	38.7
40 cm	11.1	19	26.3	32.5	37.8	42.2

Fabric #25034

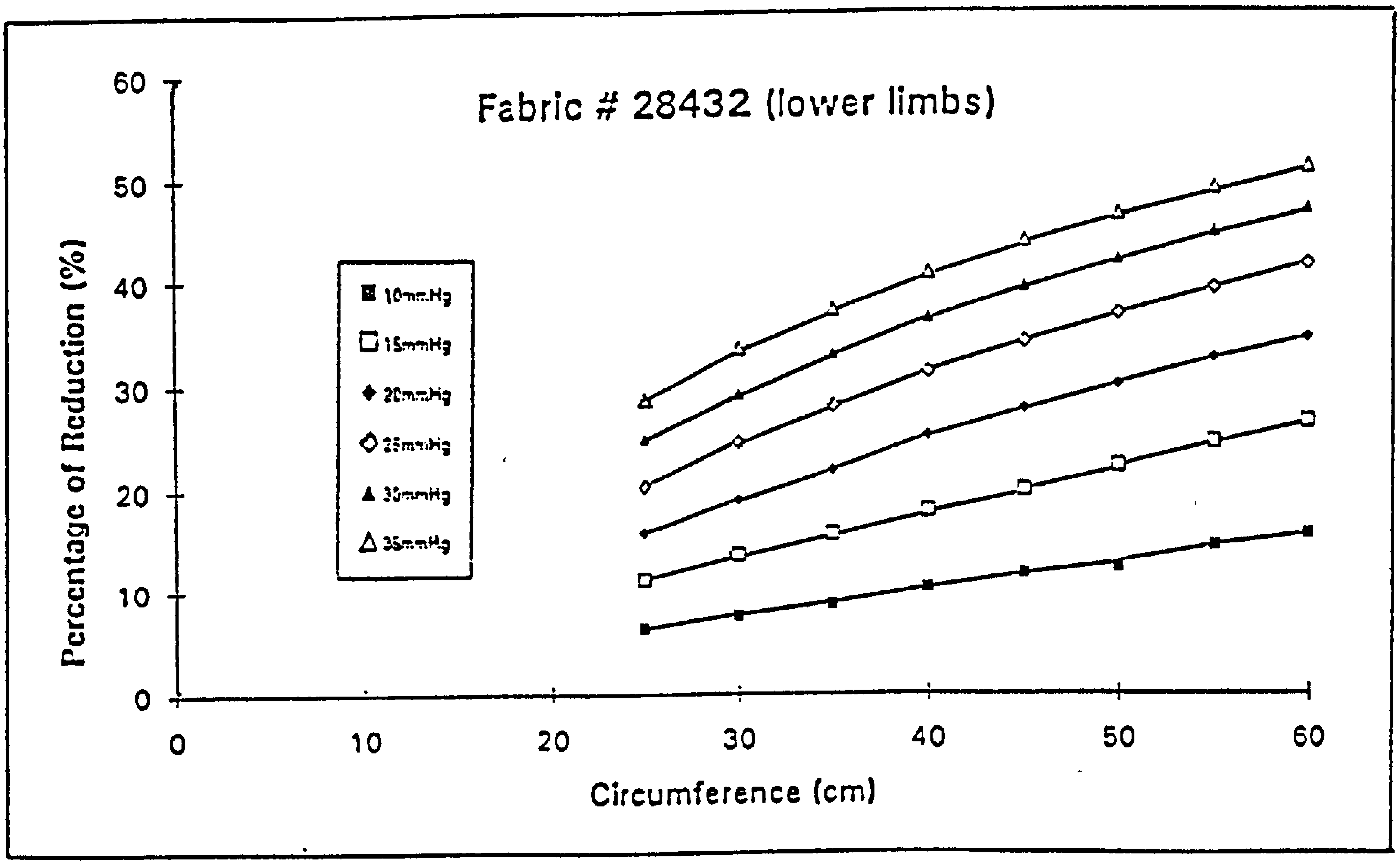
Skin-Garment Interface Pressure

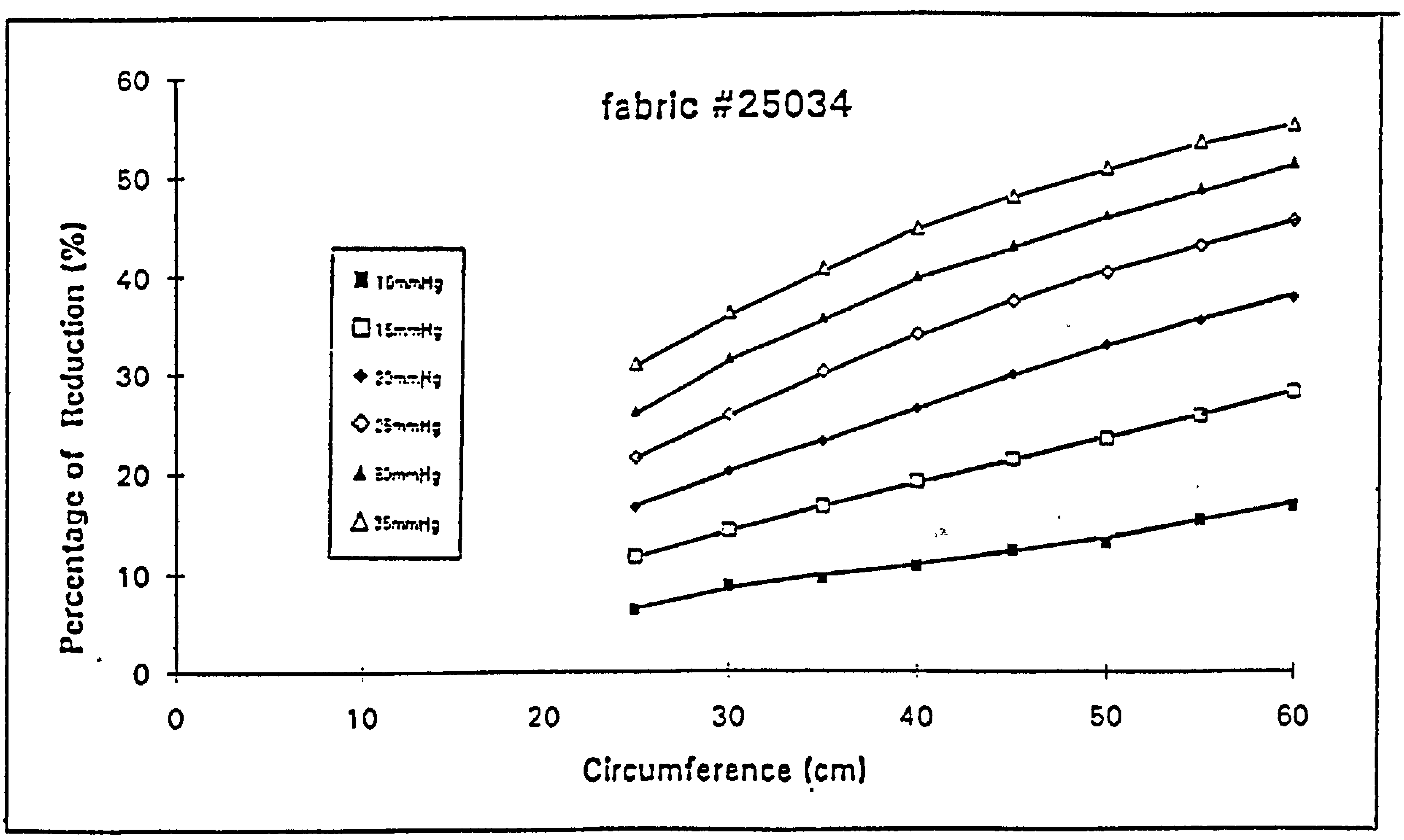
Circumference of Limbs	10 mmHg	15 mmHg	20 mmHg	25 mmHg	30 mmHg	35 mmHg
15 cm	4.3	7.3	10.4	13	16.7	20.1
20 cm	5.7	10.1	14.4	18.3	22.4	26.3
25 cm	7.1	12.4	18	23	28.1	32.9
30 cm	8.5	15.4	21.3	27.5	33.2	37.7
35 cm	10	18	24.9	31.3	37.6	42.4
40 cm	11.7	20.1	28.2	35.4	41.4	46.2

Table 3.18 The Percentage of Reduction (Reduced%) of Pressure Garment for Different Sizes (cm) of Upper Limbs at Different Pressure (mmHg) Range

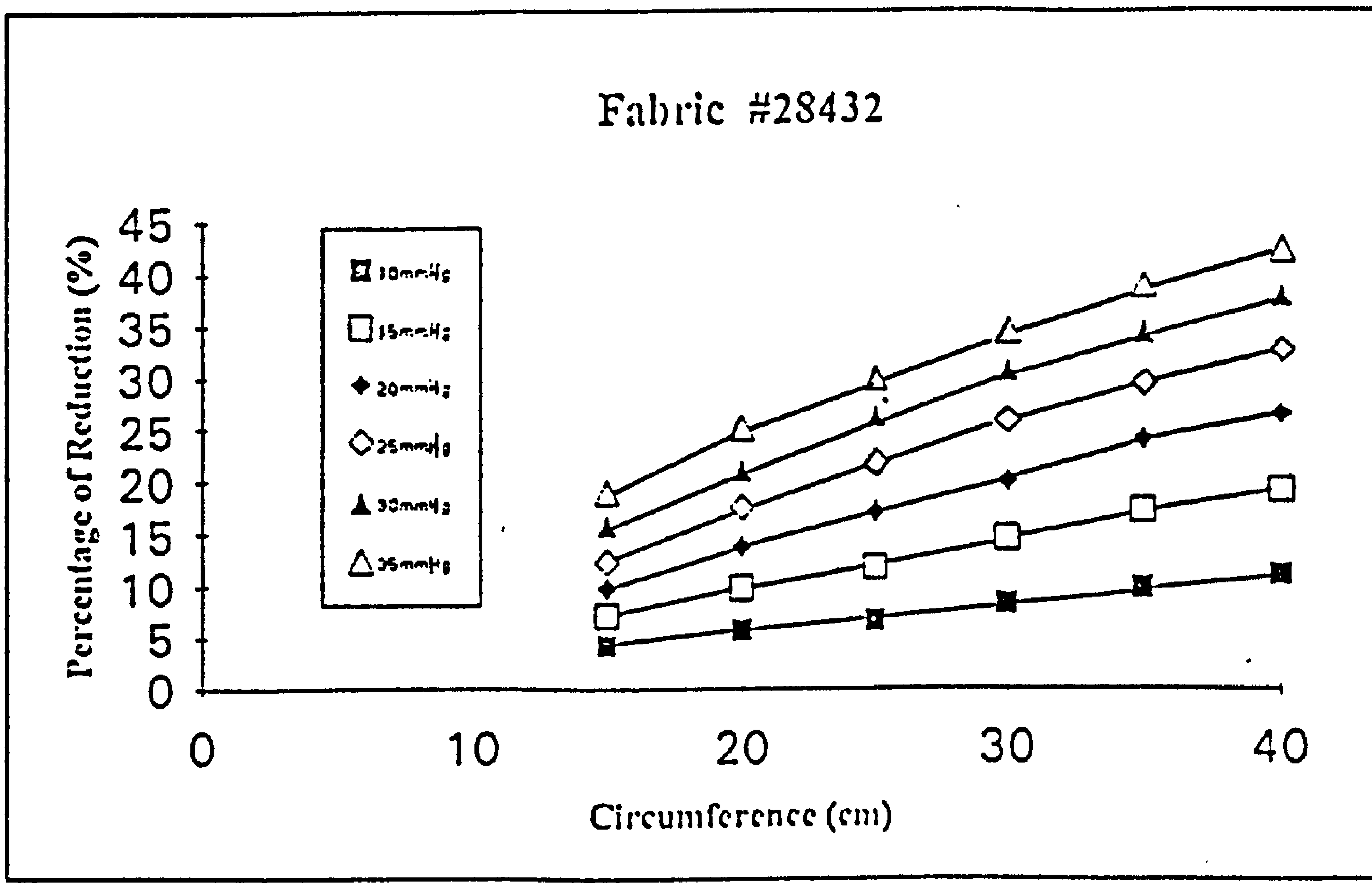
The relationship between the size of the human limbs and the reduced percentage of pressure garment at various levels of skin-garment interface pressure is also indicated by Graphs 3.19 and 3.20 for the lower limbs and upper limbs respectively. By referring to these graphs, an appropriate percentage of reduction could be suggested to the therapists for the making of pressure garments.

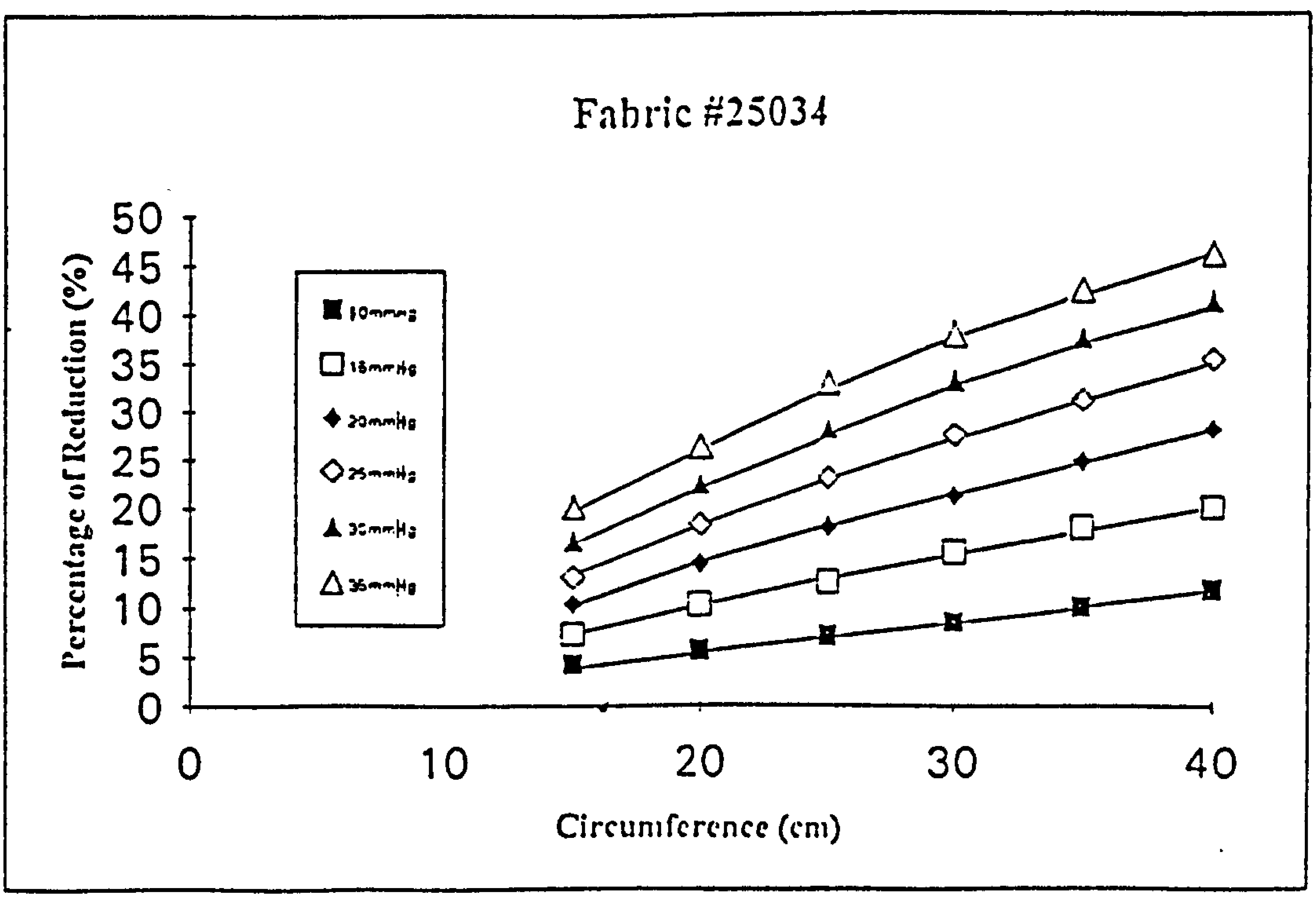
To make the drafting of pressure garments simpler and easier, the reduced percentage of pressure garments was further converted into the acutal size of pressure garment, thus the correct size of pressure garments can be found more directly for a given size of limbs and a given range of skin-garment interface pressure. Graph 3.21 and 3.22 indicating the relationship between the size of pressure garments and the size of human limbs for various skin-garment interface pressure.



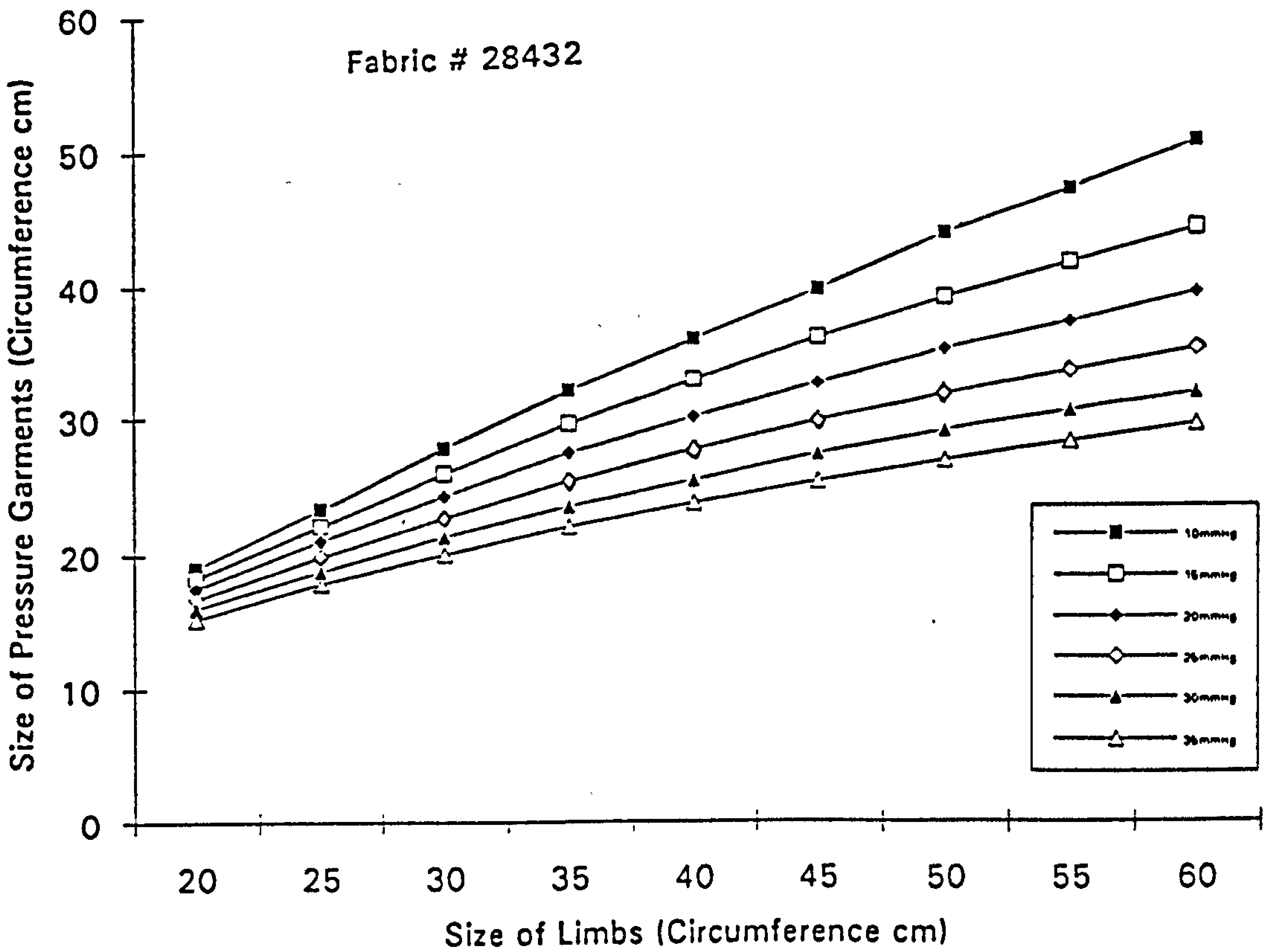


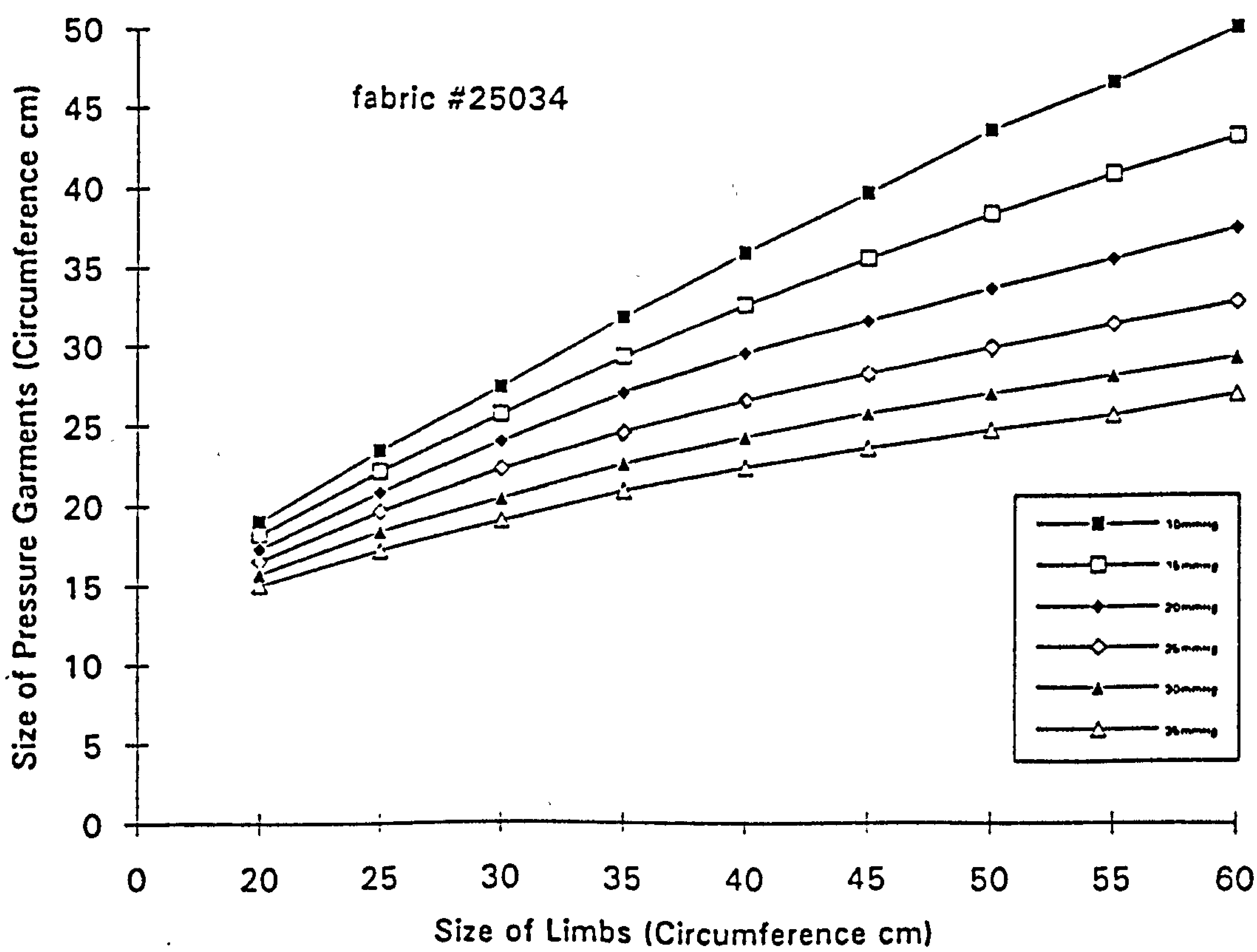
Graph 3.19 The Percentage of Reduction (Reduced %) of Pressure Garment Vs Different Sizes (cm) of Lower Limbs for Different Skin-Garment Interface Pressure (mmHg) Ranges



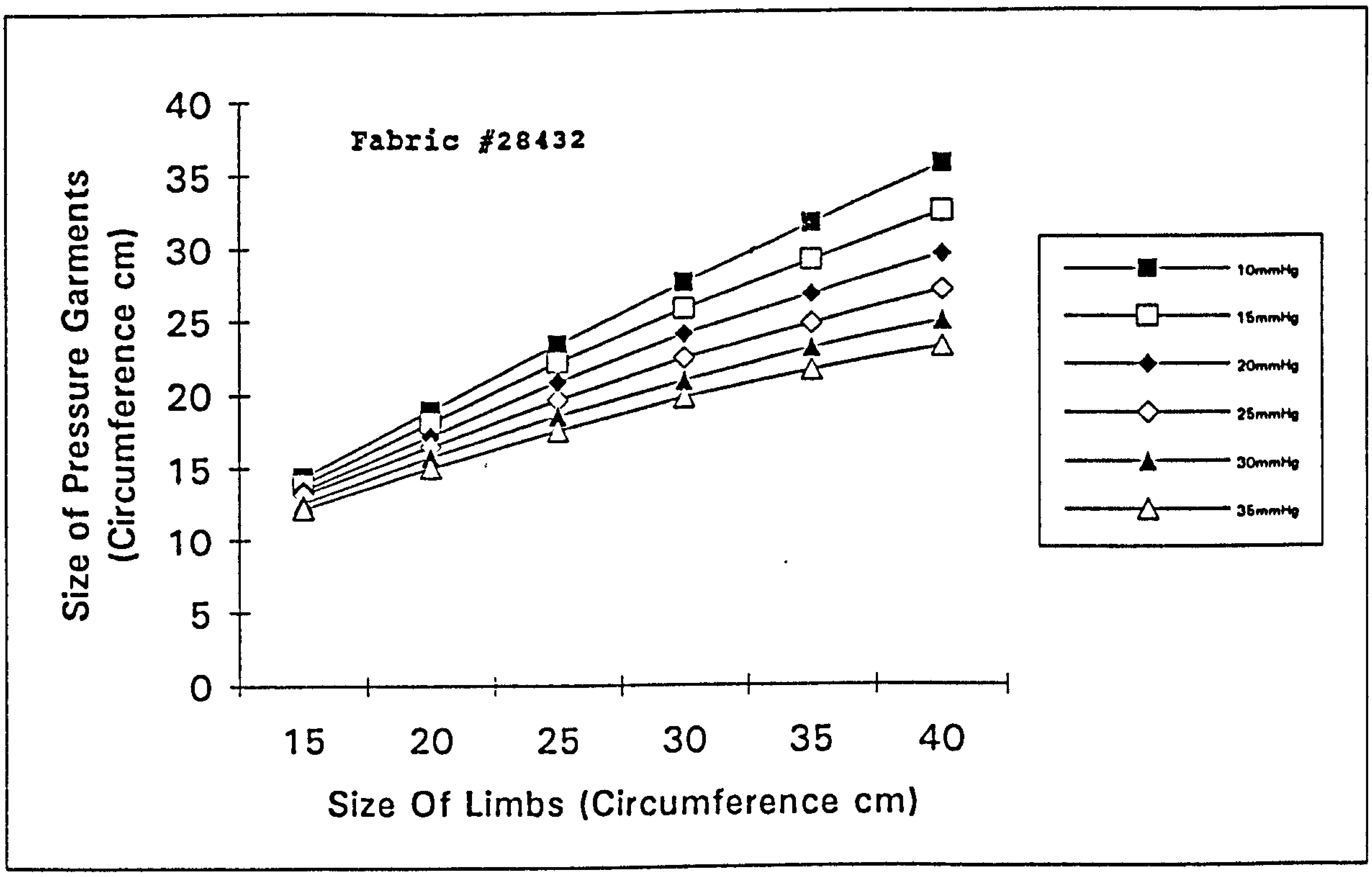


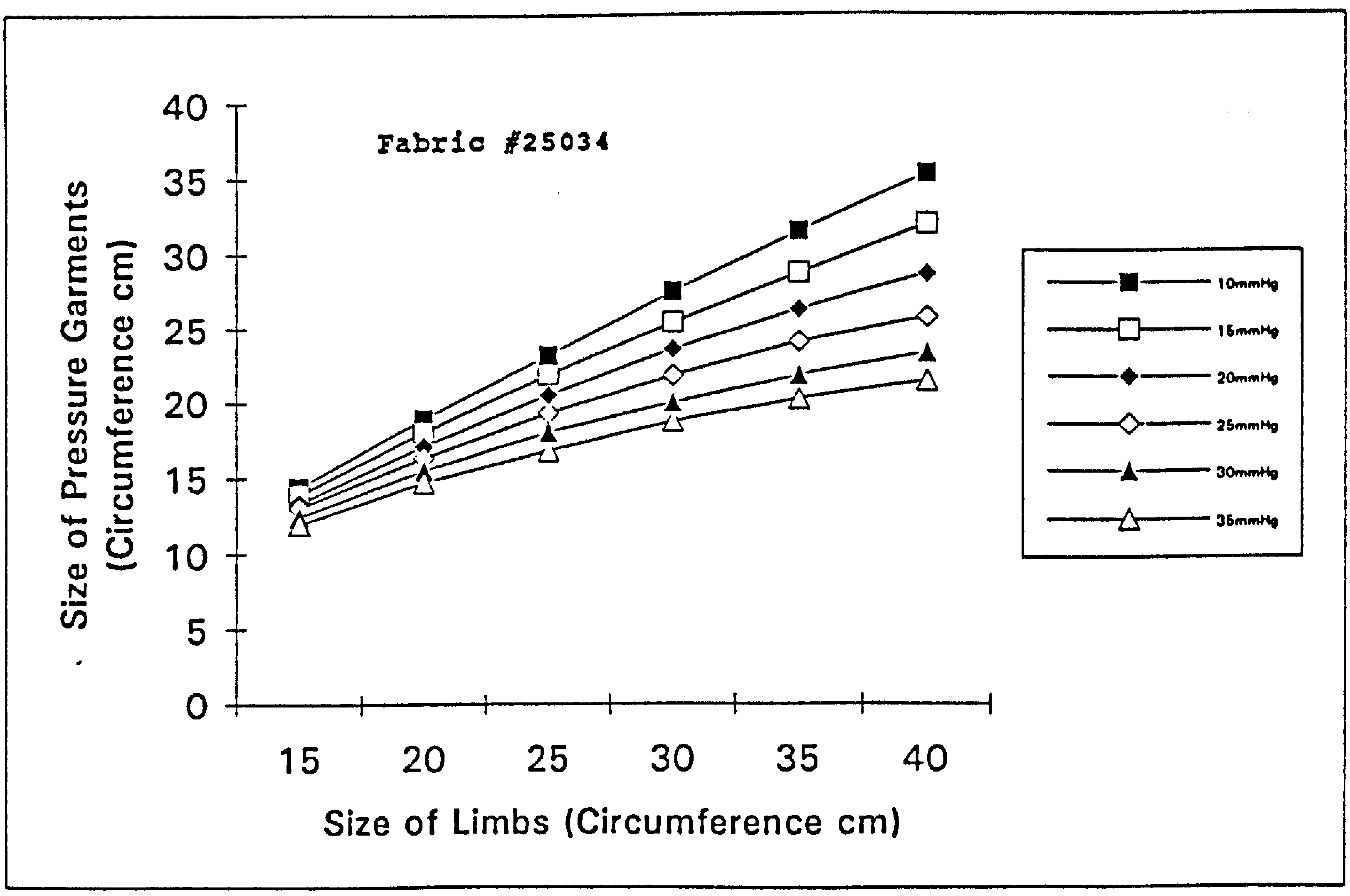
Graph 3.20 The Percentage of Reduction (Reduced %) of Pressure Garment Vs Different Sizes (cm) of Upper Limbs for Different Skin-Garment Interface Pressure (mmHg) Ranges





Graph 3.21 The Size of Pressure Garment (cm) Vs Different Sizes of Lower Limbs (cm) for Different Skin-Garment Interface Pressure (mmHg) Ranges





Graph 3.22 The Size of Pressure Garment (cm) Vs Different Sizes of Upper Limbs (cm) for Different Skin-Garment Interface Pressure (mmHg) Ranges

3.5 SUMMARY

By using the fabric tension characterisitics and based on the principle of the Laplace Law, it is possible to work out a correct size of prestretch garment to result in a given pressure for effective medical treatment.

Based on the tension of fabric recorded from an Instron Tensile Strength machine, the possible interface pressure created by the fabric compression over a curve surface can be worked out by the Laplace Law : $P = T/R$.

Garment compression exerted on a simple cylindrical tube model was examined by using a pressure transducer Oxford MKII. The tests were performed on different sizes of tube models with size ranges similar to the size of human limbs, and the size of pressure garment samples were made based on the sizes of the tube models; their finished measurement was 5% to 35% (at 5% intervals within the range) smaller than the circumference of each size of the tube models.

As illustrated in Table 3.3 and Graph 3.1, the test result shows that based on the compression created by the pressure garment of the same size; the pressure induced on the cylindrical tube was reduced when the size of the tube is increased, this correlated to the theory of the Laplace Law.

It was also noted that the interface pressure induced by different sizes of pressure garments became similar (all below 10mmHg) when the size of tube was above 100cm circumference in size. On the other hand, when the tube size is very small (e.g. below 10cm in circumference), a small change in the size of pressure garment will have much more effect on the interface pressure.

The experimental result (as shown in graph 3.3) also indicated that the interface pressure measured from each size of the cylindrical tube model is basically directly proportional to the reduced percentage of the pressure garments, but some sort of pressure exists even when there is no extension on the pressure garment. This kind of contact pressure was higher when the circumference of the tube is smaller.

To compare the pressures calculated from theory and those measured from the tube models, it is observed that they both have great changes on pressure when the circumference of interface surface is small, while the pressure change is comparatively smaller when the circumference becomes bigger. In general, the experimentally-determined pressures of both tested fabrics are quite near to the calculated values particularly in the medium range of garment stretch and larger size of tubes. Greater variations occur only in the case of small size tube models.

The graph of Tension / Circumference against Pressure (see Graph 3.11) gives a straight line by linear regression, most of the experiment data points lie in linear form on the graphs especially when the pressure focusing on the range 5mmHg-40mmHg, this indicates that the pressure is proportional to the tension of the fabric at the experimental range of extension .

The relationships between the Pressure and Fabric Tension can be represented by the equation :

$$T/C = A + BP \quad \text{or} \quad T = (A+BP)C$$

where T = Fabric Tension

C = Circumference of tube

P = Pressure

A = the intercept (indicates the amount of contact pressure)

B = the slope of the Pressure Vs Fabric Tension graph

Because of the contact pressure of pressure garments, the line of the graph 3.12 do not pass through the origin as would be expected by theory. However, it was noted that the values of A and B derived from the two tested fabrics are almost the same, it is expected that the same constant A and B can be used for the calculation.

To make a comparison between the pressure recorded from the upper and lower limbs of the human body to the experimentally determined pressure on the tube models; the average pressure measured on the upper limbs of the human body is 10% lower than those measured from the tube model, but the average pressure measured on the lower limbs of the human body was only 5% lower than those measured from the tube model. Such differences between the upper and lower limbs most probably are due to the limbs changing size upon the compression of pressure garments. The difference of interface pressuer become higher when the size of limbs is more affected by the garment compression.

Due to the pressure measured on the human body being slightly lower than those obtained on the experimental tube model (i.e., $P_{human} = R\ P_{tube}$, where R = Ratio of the slope of pressure curves between the human and tube model), a correction of the pressure value is made before the application of the equation.

Based on the equation : $T = (A + B\ P_{human} / R)\ C$,
the amount of fabric tension for a given pressure and a given size of limbs could be estimated, and the amount of fabric stretch can be determined by co-relating to the load-extension curves of the elastic fabrics. By converting the stretch percentage of elastic fabric into the reduced percentage of the pressure garment, the relationship between

the size of human limbs and the reduced percentage of the pressure garment at various level of skin-garment interface pressure can be found. Different sets graphs (see Graph 3.19-3.22) were made for recommending a correct size of pressure garment to the therapists for the cutting and drafting of pressure garments to patients.

As the load-strain relationships measured may vary with specimen width and guage length, the changes in aspect ratio of pressure garments may affect the fabric compression even though the elastic fabric undergoes same amount of stretch percentage. To study the tensile strength of fabric specimens of different aspect ratio by cut-strip tests, it is observed that fabric tension is slightly affected by the aspect ratio of the specimens due to the waisting effect of the elastic fabric under strain. However, when the waisting of the stretched fabric was eliminated in the fabric loop test, tension force per unit width of the specimen at different aspect ratio was found to be fairly constant. As the pressure garment for human limbs is mainly in the shape of a fabric tube, it is believed that fabric compression would not be much affected by the change of aspect ratio.

CHAPTER FOUR:

EVALUATION OF SEAMING METHODS FOR PRESSURE GARMENTS

4.1 INTRODUCTION

Pressure garments are tailored to individual body sizes, cut and sewn construction methods with seams formed by sewing with thread being the most important technique used in joining garment parts. As the garments are made up with the component sections joined together by stitched seams, failure at the seams leads to a reduction in serviceability even though the fabric in the rest of the article is in good condition.

The performance of a seam assembly is affected by many variables including the construction and fibre content of the fabrics and threads, seam type, stitch type, seam allowance, sewing direction, various features of the sewing machine, and operators skill etc. A lot of studies and research on seams have been published. These include studies on seam strength, seam construction, seam properties and the effect of seam on fabric properties etc. (Burtonwood B. 1966/67) [19], (Crum R. T. 1983) [20], (Howarth W.S. 1966) [21], (Hurt F.N. 1976) [22], (Gardner F.F. 1978) [23].

The general characteristics of a properly constructed seam are strength, elasticity, durability, security, and good appearance. These characteristics must be balanced with the properties of the materials to be joined to form an optimum seam. The end use of the item will govern the relative importance of these characteristics, and selections of the seam or stitch type should be based on these considerations.

Pressure garments are functional garments designed for medical purposes and are normally used under prolonged stress. The stress across seams is related to the size of the wearer and the fit of the garment, the more close fitting a garment, the greater stress is put on the seam. Since pressure garments are subjected to appreciable stress during wear, seams with the required strength and extensibility are particularly important.

As the garment has to be worn day and night, and fit like a second skin on the patient, the comfort factor becomes very important to make the continuous wearing of pressure garments possible. The seams for making the garments must be smooth and comfortable; and cause no irritation to the interface skin area. In order to maintain the effectiveness of pressure garments, the compression produced by the elastic fabric should not be much affected by the seam, and it would be ideal if the interface pressure on the seamed area could be similar to the interface area without the seams. If the quality of a seam is so good that little or no change will occur in the interface pressure, the seams of a pressure garment could be designed to be situated on the patient's body even on the scarred areas and pressure garments could be cut and sewn in a more flexible manner.

Fabric for pressure garments must be soft and elastic, it should fit the body contours as well as produce the required compression on the human body. Stretchable Lycra fabrics such as Lycra net, powernet or bobbinnet are commonly used for the making of pressure garments. The properties of such elastomeric fabrics are very complicated: their properties will depend upon the fibres and yarn used, the fabric structure, the knitting and finishing variables, and also the properties of the elastomeric components (Meredith R. 1971) [24]. The different levels of elasticity and strength of the materials will give varying degrees of fabric tension and thus induce different degrees of pressure on patients. The Lycra knitted fabrics are preferred for their high stretchability and only the types of stitch and seam having high elongation will be suitable for joining them together.

Based on the requirements of pressure garments, the seams of pressure garments should be neat, with sufficient strength and elasticity, compatible to the properties of the elastic fabrics being sewn, and also with mimimum bulkiness to avoid disturbance on the skin and garment interface pressure.

As described in chapter two, several kinds of stitch and seams are currently used to join the seams of pressure garments, these including the two thread zig-zag lockstitch (B.S.304), the covering stitch (B.S.605) and the stitch B.S.504. In order to select more suitable seams for the making of pressure garments, the above three types of stitch together with the 3-point zig-zag stitch (B.S.308) were examined in this study.

Even though Tubigrip is another common material for making pressure garments, it is not popular to cut and sew Tubigrip for made-to-measure pressure garments especially for manufacturing inside hospitals. This is because the cut edges of Tubigrip are very unstable and most Tubigrip is available in tubular form or ready-made garments. Therefore the investigation in this chapter will focus mainly on the seaming of Lycra fabrics only, the two Lycra fabrics #28432 and #25034 are used for this part of the investigation.

The methods used in the investigation of the two fabrics fall into two categories: 1) to measure the physical properties of the seams related to their suitability for making pressure garments; the testing carried out encompassed the breaking strength of seams, breaking extension, seam slippage, the stretch and recovery of seams, and seam thickness. 2) to measure the effect of seams and open edges at skin-and-garment interface pressure.

The details of the four types of seams to be tested are listed below: (See Appendix 8 for the diagram of stitch and seam construction).

<u>Seam 1</u> :

Superimposed Seam (B.S. 1.01.01), Zig-Zag Lockstitch (B.S.304).

Stitch Density: 20, 28, 40, and 55 stitches per 10 cm.

Sewing Thread : 100% Polyester

Thread Size : a) Ticket No. PP120
(for both needle and bobbin thread)
b) Ticket No. PP180
(for both needle and bobbin thread)

Seam 2 :

Superimposed Seam (B.S. 1.01.01), 3-Point Zig-Zag Lockstitch (B.S.308).

Stitch Density: 20, 28, 40, and 55 stitches per 10 cm.

Sewing Thread : 100% Polyester

Thread Size : a) Ticket No. PP120
(for both needle and bobbin thread)
b) Ticket No. PP180
(for both needle and bobbin thread)

Seam 3 :

Flat Seam (B.S. 1.01.02), Overlocking Stitch (B.S.504).

Stitch Density: 28, 40, 55, and 80 stitches per 10 cm.

Sewing Thread : 100% Polyester

Thread Size : a) Ticket No. PP120
(for both needle and looper thread)
b) Ticket No. PP180
(for both needle and looper thread)

Seam 4 :

Lapped Seam (B.S. 2.01.01), Covering Stitch (B.S. 605),

Stitch Density: 28, 40, 55, and 80 stitches per 10 cm.

Sewing Thread:

a) PP120 (for needle , looper and covering thread)
b) PP120 (for needle thread), and Ticket No. 100 Nylon thread (for looper and covering thread)
c) PP180 (for needle, looper and covering thread)
d) PP180 (for needle thread), and Ticket No. 100 Nylon thread (for looper and covering thread)

4.2 INVESTIGATION OF THE BREAKING STRENGTH OF SEAMS (UNDER TRANSVERSE LOADING)

The strength of a seam is affected by the elements including: stitch type, stitch density, thread strength, thread tension, seam type, seaming efficiency of the material. etc., W.J. Blackwood and N.H. Chamberlain have studied the factors which determine the strength of seams in knitted fabrics (1970) [25].

A preliminary study was made of the effects of variation in stitch type, thread count and stitch size. These have been investigated for two fabrics (#28432 and #25034), and four types of seams are selected for the study. Different stitch densities are used on each type of seam , and each type of seam is sewn by two sizes of sewing thread (the details of the four types of seams are listed at Section 4.1).

Each fabric and seam combination can vary so much that the optimum conditions for any particular fabric can be determined by tests carried out on that fabric. In this part of the study, we aim to study the general pattern of effects produced in the two fabric samples by some variations in the sewing process which are under the sample of the garment maker. An understanding of the effect of these variations should assist the choice of seaming conditions.

4.2.1 Specimen Preparation

To prepare the specimens for testing: rectangular pieces of fabrics were cut in the dimensions of 10cm x 7cm from both wales and courses direction with the short dimension parallel to the wales yarns for measuring the breaking force in the lengthwise direction (the wales direction is the stretch direction of the test fabrics). Two fabric pieces were placed together, face to face. A seam was stitched across the long dimension of the specimens, it is important that the seam be perpendicular to the wales of the fabrics, and some means be adopted for preventing, or at least minimising, the stretching of the elastic fabric during the seaming operation.

The stitches for seaming all the specimens must be made under uniform tension. Special care is required to adjust the stitch tension for the seam sewn by the overlocking stitch (B.S.504). This stitch is used to join the raw edges of the sewn fabrics by enclosing them in a sort of sheath or tube of close stitches. If the tension of the stitch is tight or in a state of normal balance, when such a seam is opened out flat, the raw edges of the sewn fabrics may roll up inside the sheath and form a rather bulky ridge running along the back of the seam, which prevents the latter from lying flat to form a flat seam. When smoothness of fit and better appearance are required, the stitch tension has to be adjusted to a relatively low value which enables the two sewn edges to lay flat inside the sheath when the seam is opened out.

As the seams at the edges tend to ravel during testing, especially when the stitch density is relatively low, all seamed specimens were cut in a cross shape (as per Figure 4.1). The finished width of the specimen was 5cm but an additonal extension (2.5cm in width and 3cm in length) was added at both edges. For a guage length of 5 centimeters, a line was marked 2.5cm above the center of the seamline to use as a guide for jaw placement on the Instron Tensile Tester.

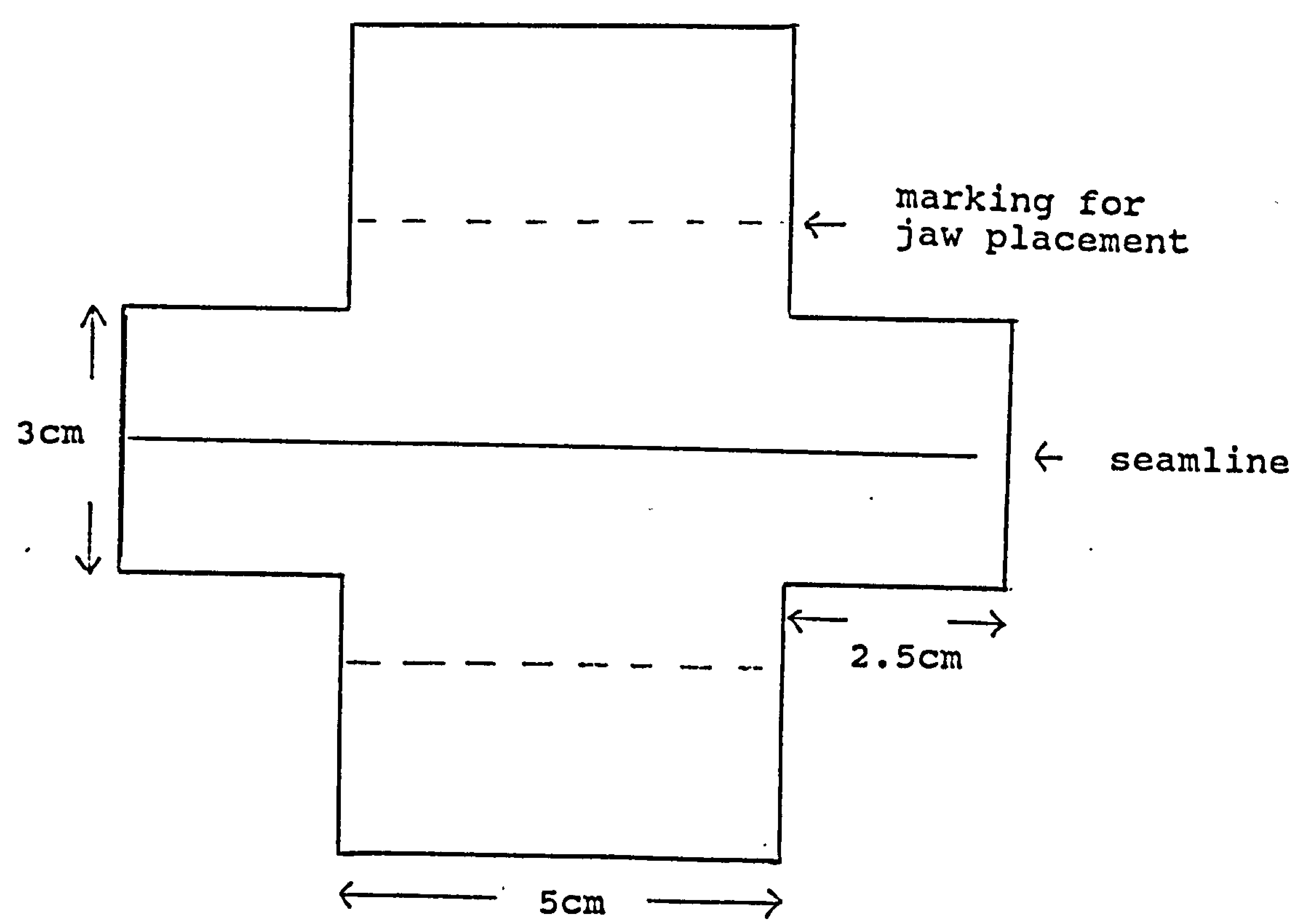


Fig. 4.1 Seamed Specimen Cut in Cross-Shape

4.2.2 Method of Test

In order to compare the breaking strength of seams, cut-strip tests (with specimens in cross shape) were used.

The specimens were mounted in an Instron Tensile Strength Machine (model 1026), as shown in Fig.4.2, manually under zero load. In all cases the specimens were extended at a constant rate of 200mm/min. The clamp width of the machines was 5cm (flat faces); and the tension load cell scales available were 5kg, 50kg and 100kg. A force was applied to the tested specimen until it broke. Values for the breaking force are read from the chart of the testing machine.

The breaking force recorded is referred to as the maximum force applied to a material carried to rupture. When a seam joining two pieces of fabric is subjected to increasing stress applied at right angles to its length, a point is ultimately reached when the seam fails by rupture of either of the sewing threads, leaving the fabric intact, or of the fabric, leaving the sewing thread unharmed. In general, seam failure is either the breakage of either the material or the thread, it is very rare to postulate a third type of break in which both sewing thread and fabric fail simultaneously.

By comparing the breaking loads of the tested specimen in relation to various stitch types, stitch density and thread sizes, the properties of the seams could be evaluated and it is most desirable to find a seam that could withstand extensions equivalent to those of the high extension knit fabric without thread cracking taking place.

Five samples were prepared for each combination of seam construction, stitch density and thread denier (400 samples in all for the two fabrics tested). The mean values of the test results for each set of conditions are summarised in Table 4.1.

Fig. 4.2
An Instron Tensile Strength Machine (Model 1026)

Fabric #28432

Sewing Thread			Stitch Densities (stitches per 10cm)														
Seam Type	Needle	Looper/ Bobbin	20			28			40			55			80		
			BSS	BT	SE	BSS	BT	SE	BSS	BT	SE	BSS	BT	SE	BSS	BT	SE
1	120	120	19.4	1	33.4%	37.2	1	64.1%	48	1	82.8%	52	2	89.7%	-	-	-
	180	180	13.2	1	22.8%	27	1	46.6%	34.4	1	59.3%	46.8	1	80.7%	-	-	-
2	120	120	25	1	43.1%	40.4	1	69.6%	50	1	86.2%	53.4	2	92.1%	-	-	-
	180	180	14	1	24.1%	27.6	1	47.6%	32.6	1	56.2%	45.2	1	77.9%	-	-	-
3	120	120	-	-	-	33.2	1	57.2%	39.8	1	68.6%	49.4	1	85.2%	51.4	2	88.6%
	180	180	-	-	-	24.2	1	41.7%	36	1	62%	45.2	1	77.9%	49	1	84.5%
4	120	120	-	-	-	46	1	72.4%	47.6	1	82.1%	52.8	2	91%	52	2	89.7%
	120	100 (Nylon)	-	-	-	42.4	1	80%	44	1	75.9%	51.6	2	89%	51.2	2	88.2%
	180	180	-	-	-	30.4	1	52.4%	35.2	1	60.7%	47.2	1	81.3%	50.2	1	86.6%
	180	100 (Nylon)	-	-	-	26.6	1	45.9%	33.6	1	57.9%	46.4	1	80%	49	1	84.5%

Fabric #25034

Sewing Thread			Stitch Densities (stitches per 10cm)														
Seam Type	Needle	Looper/ Bobbin	20			28			40			55			80		
			BSS	BT	SE	BSS	BT	SE	BSS	BT	SE	BSS	BT	SE	BSS	BT	SE
1	120	120	18.8	1	31.3%	35.2	1	58.7%	42	1	70%	47.4	1	79%	-	-	-
	180	180	12.8	1	21.3%	27.2	1	43.3%	33.6	1	56%	45.2	1	75.3%	-	-	-
2	120	120	24.2	1	40.3%	38.6	1	64.3%	46	1	76.7%	48.2	1	80.3%	-	-	-
	180	180	13.8	1	23%	26.4	1	44%	32	1	53.3%	42.4	1	70.7%	-	-	-
3	120	120	-	-	-	32	1	53.3%	38.4	1	64%	48.8	1	81.3%	50.2	1	83.7%
	180	180	-	-	-	24.2	1	40.3%	35	1	58.3%	44.6	1	74.3%	47.2	1	78.7%
4	120	120	-	-	-	39.8	1	66.3%	45.8	1	76.3%	49.2	1	82%	52.6	2	87.7%
	120	100 (Nylon)	-	-	-	36.6	1	61%	42.2	1	70.3%	47	1	78.3%	50.8	2	84.7%
	180	180	-	-	-	28	1	46.7%	33.6	1	56%	47.6	1	79.3%	48	1	80%
	180	100 (Nylon)	-	-	-	26.2	1	43.7%	31	1	51.7%	45.2	1	75.3%	45.2	1	75.3%

Table 4.1

The Breaking Strength (Kg. force) of Different Types of Seams in Relation to Stitch Densities and Sewing Thread

Key:

BSS - Breaking Strength of Seam
BT - Breakage Types :
(1) Thread breaks, fabric intact
(2) Fabric breaks, along seam edge

SE - Seam Efficiency

4.2.3 Test Results and Discussion

Seam 1 and Seam 2

The stitch density showed significant influence on the seam strength. The seam efficiency of both fabrics was very low (below or around 60%) when the stitch density was at or below 28 stitches per 10cm but there was a great improvement (seam efficiency increased up to around 80% or above) when the stitch density was increased to 55 stitches per 10 cm.

The seam failure mainly occurred at the sewing thread, leaving the fabric intact. Breakage of the fabric was found only in the fabric #28432 sewn with PP120 sewing thread and at a stitch density 55 per 10cm. The results indicated that there is no need to further increase the stitch density when the size of stitch and the size of sewing thread are already strong enough to provide a favourable strength to the seam. On the other hand, it seems quite possible to have a better seam efficiency for fabric #25034 by further increasing the stitch density or by using a heavier sewing thread. In all cases, the seam constructed with the stronger sewing thread (PP120) provided better seam strength than those made by the thinner thread (PP180).

Seam 3 and Seam 4

The test results indicated that the breaking strength was closely related to the stitch density, but the change of seam efficiency became very small when the stitch density was increased from 55 stitches per 10cm to 80 stitches per 10cm. This means that the seam strength was close to the maximum when the stitch density was around 55 stitches per 10cm. Particularly with Seam 4 of fabric #28432 sewn by the PP120 thread, the seam strength decreased instead of increased when the stitch density was higher than 55 stitches per 10 cm.

It is clearly shown that a coarser sewing thread gave better seam strength. The change of Ticket No. 100 nylon thread for the polyester looper thread had little effect on seam strength, the seam became slightly weaker instead of stronger.

For the Seam 3, all the seams of fabric #25034 failed on sewing thread. Only the seams of fabric #28432 which were sewn by thread PP120 at a stitch density 80 stitches per 10cm were found to have fabric breakage. For the Seam 4, the fabric #25034 remain unharmed unless the seams were stitched by PP120 sewing thread and at a very high density (80 stitches per 10 cm), but the fabric #28432 sewn with the same size of sewing thread broke at a lower stitch density

(55 stitches per 10cm or above). The test results indicate that the seam efficiency of fabric #28432 in general was slightly better than the fabric #25034 sewn with the same conditions.

Similar to the Seam 1 and Seam 2, to adjust the stitch density to around 55 stitches per 10 cm is good enough to provide a seam efficiency around or above 80%. Such seam performance is considered suitable for most types of garment.

4.3 BREAKING EXTENSION (UNDER LONGITUDINAL LOADING)

Lycra knitted fabrics, in general, are very extensible. As a result it often happens that, when a seam in a pressure garment is extended along its length, the extension limit of the seams is reached before that of the fabric itself.

A seam is exposed to higher stretch when the garment is put on, worn, and taken off. In addition, the seams of pressure garments are subjected to appreciable extension under the body movement of a patient. According to the patients' comments collected from the previous study (Yip Ng S.F. 1993) [11], it was found that seams are broken during the donning of pressure garments. Thus, the behaviour of seams under longitudinal stresses is of great importance in pressure garments.

Since the absolute seam strength in a longitudinal direction is not of paramount importance to a pressure garment under actual performance, it was decided to study the breaking extension of the four types of seams when stress is applied along the seam direction.

4.3.1 Specimen Preparation

All specimen were seamed in the way similar to that described in section 4.2.1, but the finished size of the specimen was 3cm in width and 16cm in length; with the long dimension parallel to the courses yarns; the seam was placed at the centre of the specimen in a longitudinal direction.

4.3.2 Method of Test

The experimental conditions and instrument used were the same as in section 4.2.2., only the gauge length for the experiment was changed to 10 cm. A force was applied to the tested specimen until seam cracking occured. The amount of seam extension at the breaking point was recorded. Five specimens with the same variables were tested for the study. The mean values of test results are summarised and presented in Table 4.2.

Fabric #28432

Sewing Thread			Stitch Densities (stitches per 10cm)				
Seam Type	Needle	Looper/ Bobbin	20	28	40	55	80
1	120	120	60	110	200	250	-
	180	180	52	100	190	230	-
2	120	120	98	146	230	250	-
	180	180	75	128	230	236	-
3	120	120	-	63	112	166	220
	180	180	-	52	64	86	120
4	120	120	-	59	95	140	205
	120	100 (Nylon)	-	60	98	160	222
	180	180	-	46	72	121	180
	180	100 (Nylon)	-	50	83	140	190

Fabric #25034

Sewing Thread			Stitch Densities (stitches per 10cm)				
Seam Type	Needle	Looper/ Bobbin	20	28	40	55	80
1	120	120	60	96	160	280	-
	180	180	50	88	145	255	-
2	120	120	95	140	250	290	-
	180	180	70	120	230	275	-
3	120	120	-	60	100	180	210
	180	180	-	50	56	78	118
4	120	120	-	60	94	130	215
	120	100 (Nylon)	-	58	102	140	250
	180	180	-	48	70	105	180
	180	100 (Nylon)	-	50	76	135	190

Table 4.2 The Percentage of Extension of Different Types of Seam (Stretch Longitudinally) at Breaking Point

4.3.3 Test Results and Discussion

The two fabrics tested have similar test results. All types of seams showed that the breaking extension increases when the stitch density increases. For Seam 1 and Seam 2, the breaking extension was around 100% or above when the stitch density was 28 per 10 cm. Such percentage of extension is considered quite acceptable for the seams used on pressure garments. When the stitch density of Seam 1 and Seam 2 was increased up to 55 per 10 cm, the seam broke when the breaking point of the fabric was reached, this means that a further increasing of stitch density would be unnecessary.

For the other two types of seams (Seam 3 and Seam 4), the stitch density has to be adjusted up to around 55 per 10cm if the breaking extension required is to be 100% or above. The test results indicated that these types of seams have fairly low breaking extension if the stitch density was low (for example below 40 stitches per 10 cm).

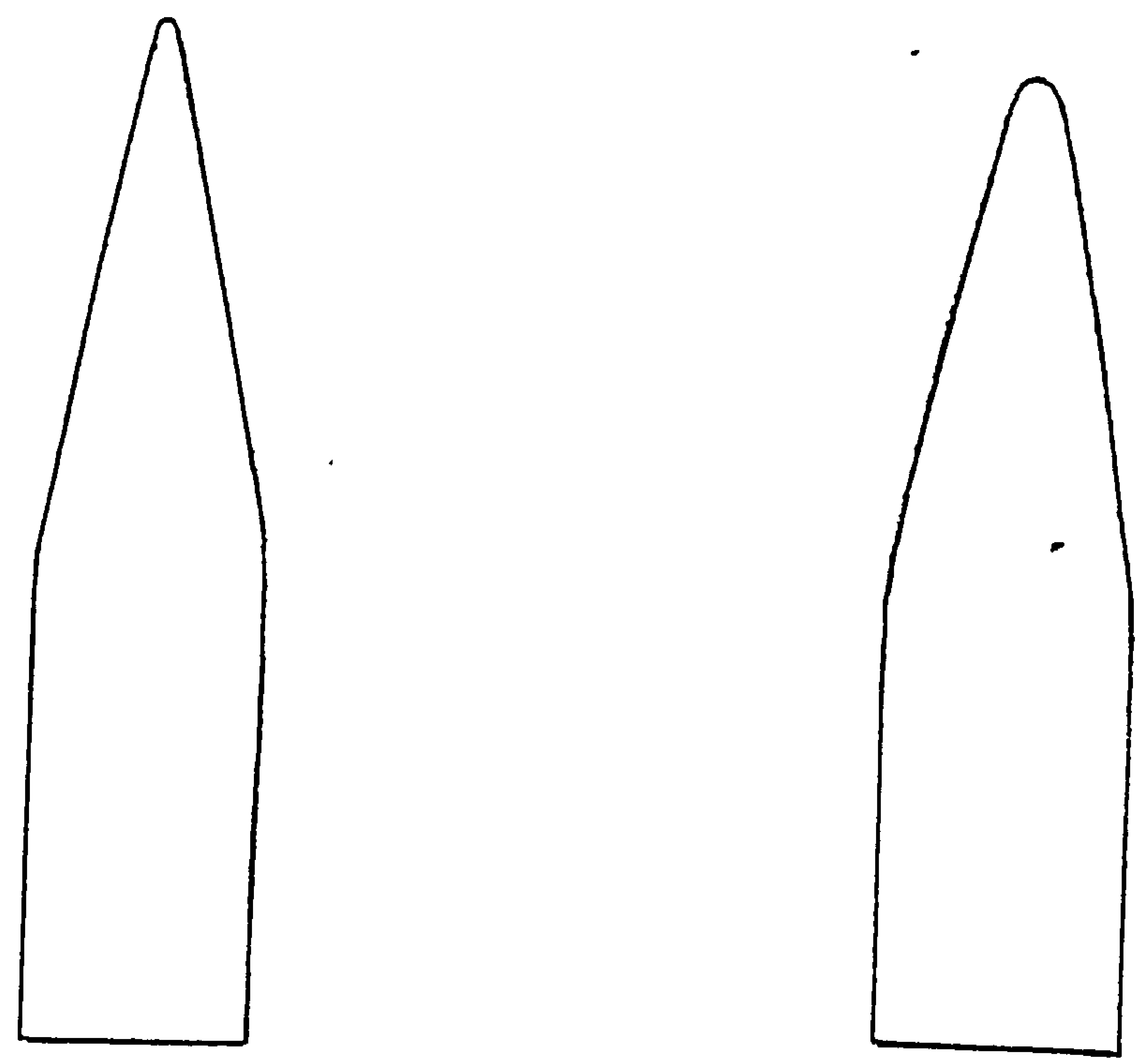
The size of sewing thread was significant to the breaking extension of seams. The breaking extension decreases when a thinner sewing thread (PP180) was used, this happens to all types of seams tested. For the Seam 4, there is no significant difference in breaking extension when a nylon sewing thread was used to replace the polyester looper thread, the breaking extension increased only very slightly for this thread change.

4.4 NEEDLE DAMAGES

The incidence of fabric damage near the seams of pressure garments has drawn attention to the need for more understanding of needle damage caused by sewing. Needle damage is the most common phenomenon when assembing knitted garments especially those made from fine knits. The strength and appearance of the seam will deteriorate when such damage occurs.

A lot of studies have been carried out to investigate the problem of seaming damage in knitted fabrics and related the problem of needle damage to the sewing needle rather than fabric structure (Blackwood W.J. 1970) [25]. It also has been reported that the risk of failure can be minimised by adjustment of stitch density, bight, and thread tension (Parker, R. 1974) [26]; the correct choice of machine types and machine settings, as well as appropriate lubrication of fabrics is also important (Gampe, Heinz 1986) [27].

This part of the study still focused on the two types of warp knit fabrics (#28432 and 25034) and the four types of seams (as listed section 4.1). Two needle sizes (Singer No. 9 and No. 14) with two different point types (a) normal set point, (b) medium ball point, were employed in the test for each type of seam. Figure 4.3 showed the diagram of needle points.



(A) Set-Point (B) Ball Point

Fig. 4.3 Sewing Machine Needles

Since the level of fabric damage is affected by the penetration force, and this is directly related to the sewing speed, the test were performed at two machine sewing speed: 1000 rev/min (low) and 2000 rev/min (high) for Seam 1, 1500 rev/min (low) and 2500 rev/min (high) for Seam 2, 1500 rev/min) and 3000 rev/min (high) for Seam 3 and Seam 4, all under normal sewing conditions. A tachometer was placed in contact with the balance wheel while the sewing machine was running.

4.4.1 Specimen Preparation

The seam specimens for the study were made on fabrics cut to size 10cm x 25cm with the long dimensions parallel to the courses direction, lines were marked on the two ends of the seam specimen so that the spacing between the two lines was exactly 20cm. All the seams were sewn in the course direction of the fabric.

4.4.2 Method of Test

The objective of the test was to determine the percentage of needle damage by counting the number of distinct holes in the fabric owing to complete or partial yarn breakage when a certain number of stitches is sewn.

The stitched specimens were placed under a magnifying glass and stretched manually to expose any hole caused by a broken yarn. The thread of the seams was removed before assessing the damage. Each type of seam was repeated three times to ensure sufficient data for analysis.

4.4.3 Test Results and Discussion

No obvious damage was observed from the two fabrics sewn with the four different types of seams. Only two cases have been found with the yarns slightly damaged by the sewing needle; this occured on the fabric specimens #28432 which is sewn by covering stitch with high stitch density (80 s.p. 10cm) by set point needles at size 14 and at high sewing speed (3000 rev/min).

These results may be explained by the fact that, for the Lycra fabrics used for the study, the yarns are very strong and the spaces between loops and/or yarn intersections are fairly large. Thus, as the needle penetrates the yarns, instead of passing through the yarn, the needle will take the path of lower resistance through the gap between the yarns without causing damage. When the specimens were stitched by relatively high density at high speed, it is still possible to have the sharp tip of the needle damage the yarn structure by chance, but such cases only happen two times at fabric #28432, and it is not found at the open structure fabric #25034 at all. Fabric damage is not found with the two tested fabrics if they are sewn by a ball point needle, because the round tip of ball point needles may deflect and push the yarn out of its path.

4.5 SEAM SLIPPAGE

When two pieces of fabric, joined together with a row of stitching to form a seam, are strained at right angles to the seam at strains below the breaking point of the seam, the fabric at both sides of the stitching may distort and yarns within the fabric slide away from the seam, and seam slippage arises. Such slippage results in garment failure at a seam, which is not readily repairable by reseaming.

The problem of seam slippage principally arises from the construction of the fabric. A fabric of relatively open nature allows the yarns freedom of movement and those constructed with slippery yarns more readily suffer seam slippage. The work of Morris and Brian (1975) [28] illustrated that the amount of seam slippage is affected by the stitch density, seam allowance and the thread tension.

In this part of the study, samples were produced to test the effect of various stitch and seam types on seam slippage on the two tested fabrics used for making pressure garments. The same kind of seam specimens (as listed on section 4.1) were used for the investigation. As the behaviour of knitted fabric under stress is very complex, to compare the seam slippage on knitted fabric becomes more difficult. The change of loop shape as the knitted fabric is extended should be considered when determining the amount of seam opening on the tested specimen.

Normally, seam slippage is compared by applying a fixed weight to the seamed specimen and the extent to which the seam opens is measured. The choice of the weight applied to the seamed specimen is dictated mainly by the weight and the end-use of the fabric, for example, 18kg weight can be applied to garment specimen where considerable seam strength is required. However, in order to design a test closer to actual performance-in-use, seam slippage in this part of study was measured based on a fixed fabric extension instead of a fixed load.

4.5.1 Method of Test

To compare the seam slippage of the seams used for making pressure garments, a grab-test was selected for the investigation. The test method is derived from ASTM D-434.

Rectangular fabric specimens were cut 9cm long and 10cm wide, and with the shorter sides of the specimen parallel to the wales direction. Two fabric samples were seamed together at the long sides by a row of stitches parallel to the fabric edges and with a seam allowance of 1cm from the cut edges of the fabrics. It is important that the stitches be made under uniform tension and that the seam be perpendicular to the wales direction. Frequent checks were made to ensure a balanced stitch was formed at all times.

The specimens were mounted in an Instron Tensile Strength machine, under zero tension. The clamp width of the machine was 2.5cm and the gauge length was 7.5cm. Care was taken to ensure that the clamps were properly aligned and parallel, and the specimen was secured symmetrically in the clamps with the seam midway between and parallel to the edges of the two clamps.

Specimens were held between the jaws and extended. The cross-head of the Instron tester was driven at a speed of 200mm/min and the load cell used was 5Kg. In order to measure the amount of slippage at the seam more accurately, a relatively high chart to cross-head ratio of 4:1 was used.

The test was started by applying tension at a constant rate of extension to the fabric without a seam (specimen size 16cm x 10cm) and the load-elongation curve of the unseamed fabric sample is recorded. Then the test was repeated on the seamed specimen on the same chart. Tension was applied across the seamed specimen, beyond the point where the seam broke, and the resulting load-elongation curve for the fabric with the seam was recorded on the same chart.

Based on the fixed extensions of the specimens, the amount of seam slippage can be measured. The distance between the recorded load-elongation curves was measured from the point where the specimen was extended by 20%, 30%, 50%, and 100% to find out the amount of slippage which occured.

4.5.2 Test Results and Discussion

Seam 1 :

Slippage at seams for fabrics #28432 and #25034 (as shown in Table 4.3) showed similar behaviour. The slippage of the seam was not so high (not more than 2.3mm) when the extension was within 30%, this amount of slippage is within the normal acceptable range, but the slippage increases when the stretch percentage of the specimen increases, the slippage being up to 3.8mm when the extension of the specimen was 100%. It is also noted that the seam slippage is affected by the stitch density; the lower the stitch density, the higher will be the seam slippage. Comparing the seam slippage of the fabric #25034 to the fabric #28432, it was found that the fabric #25034 has relatively higher slippage, this may be due to the fabric #25034 being more open in loop construction. Due to the structure of the stitch with thread interlocking only at the turning point of the zig-zag pattern, both seam grinning as well as slippage were observed at the seamed specimens.

Seam 2 and Seam 4 :

The specimens made of these types of seam do not show slippage in the extension range from 20 to 100 percentage, this indicates that the seams are very strong for the two tested fabrics. Instead of slippage occuring at the joined seams, it is observed that, when the seam is made of stitches (e.g. the covering stitch) of relative high density and large width, then a relative higher force is required to stretch the seamed specimen to the same extension. For example, the force to stretch an unseamed fabric #25035 to 100% is 2.8 kg, but to stretch the specimen seamed by covering stitch (80 s.p.10cm) to the same 100% extension require a force of 3.05 kg, that means an additional force of 0.25 kg is necessary. This proves that the width and rigidity of seams have influence on the extensibility of a seamed specimen, especially when the gauge length of the specimen is small. If the seam is wide and rigid, then the seam area is non-extensible, and it is the fabric beyond the seam area that will sustain the higher stretch percentage. Thus a higher than expected tnsile force is required to extend the seamed specimen to the required extension.

Seam 3 :

For the seams made of the overlocking stitch, little or no slippage is found on both fabrics when the specimen is stretched 20-30%. When the amount of extension is increased, seam slippage increases, similar to the Seam 1, the slippage is higher when the stitch density is lower, and the slippage occurring on fabric #25035 is slightly higher than that occuring with fabric #28432. The maximum slippage found on fabric #25034 sewn with stitch density 28 s.p. 10cm was only 1.8mm at 50% extension, which is not significant for a very extensible fabric like the Lycra net. When the extension of the specimens was up to 100%, the slippage was still around 1-2mm when the stitch was of medium density (i.e., 40-55 s.p.10cm), only when the stitch density was fairly low, e.g. 28 s.p.10cm., did the amount of seam slippage increase to 2.5mm.

Fabric #28432	Seam 1				Seam 2	Seam 3				Seam 4
	20	28	40	55 s.p. 10cm	20-55 s.p. 10cm	28	40	55	80 s.p. 10cm	28-80 s.p. 10cm
Seam Slippage at 20% Extension	1.3	1.1	1	0.8 mm	Nil	Nil	Nil	Nil	Nil	Nil
Seam Slippage at 30% Extension	1.8	1.6	1.5	1.3 mm	Nil	0.8	0.5	Nil	Nil	Nil
Seam Slippage at 50% Extension	2.4	2.1	1.8	1.5 mm	Nil	1.5	1	0.6	Nil	Nil
Seam Slippage at 100% Extension	3.4	3	2.5	2 mm	Nil	2.3	2	1.5	1	Nil

Fabric #25034	Seam 1				Seam 2	Seam 3				Seam 4
	20	28	40	50	20-55	28	40	55	80	28-80 s.p. 10cm
Seam Slippage at 20% Extension	1.8	1.5	1	0.8 mm	Nil	0.5 mm	Nil	Nil	Nil	Nil
Seam Slippage at 30% Extension	2.3	1.8	1.3	1.2 mm	Nil	1 mm	0.5	Nil	Nil	Nil
Seam Slippage at 50% Extension	2.8	2.3	1.8	1.5 mm	Nil	1.8 mm	1.3	1	0.8	Nil
Seam Slippage at 100% Extension	3.8	3.2	2.3	2 mm	Nil	2.5 mm	2.1	2	1.5	Nil

Table 4.3 The Slippage (mm) of Different Types of Seams under Various Percentage of Extension

4.6 ELASTICITY AND RECOVERY

For a very extensible fabric like the Lycra net used for making pressure garments, to consider only the extension of the fabric at break is of little actual performance value, measurement of seam extensiblity is of greater importance. Ideally we should have the extensibility of the seam identical to the extensibility of the fabric being sewn especially if the strain force is applied along the seamline. Lack of seam extensibility results in the load being concentrated on the seam giving seam breakage and garment failure and therefore of limited application in the garment construction.

It is not enough to consider merely the breaking load and the extension of the seam at break, it is important to appreciate the interrelation of load and extension, and to consider how the seam behaves when loaded or extended under conditions which do not reach breaking point. The measurement of the elastic behaviour of seams is the assessment of their ability to recover strain-induced energy, and to recover their original dimensions following a known extension. The power of recovery from deformation may be defined as "Elasticity" from the standpoint of textile science.

Elastic recovery is usually measured as recovery from strain, but the position is not particularly simple. For most cases, recovery is better from low strains, wheareas at high strains there is often a different order of recovery. Perfectly elastic seams will have an elastic recovery of 100%, while materials without any power of recovery will have a recovery of zero.

The elastic recovery of seams is not an easy matter to determine. One of the chief difficulties is that the recovery is not immediate, but there is an elastic after-effect. Another difficulty is that the stitch and/or thread involved in the seam construction may vary along the seam. Hence the time factor must be taken into account and it is necessary to specify the conditions under which the elastic recovery is determined. Because of the greater deformability of knitted fabrics, the effect of seam opening or grinning is shown more readily and may appear even under lower stresses. Seam grinning affects the elasticity and recovery of seams particularly when the strain is applied normal to the seam direction. It should be noted that the extension of a seam comprises two components, namely the elastic and frictional components. The elastic extension component is recoverable. The frictional component is not recoverable as the extended component parts slide on one another and do not return to the original state when the distorting force is removed.

4.6.1 Method of Test

4.6.1.1 Along Seam Direction

In order to examine the elastic behaviour of the four types of seams used on the manufacturing of pressure garments, cut strip tests were used.

To prepare the seamed specimen for investigation, rectangular fabric specimen were cut 18cm x 10cm, with the long side of the specimen parallel to the wales direction. Two fabric specimens were seamed together at the long sides at a distance 1cm from the fabric edges. The seamed specimen was cut to a finished width of 2.5cm with the centre of the seam at the centre of the specimen, and the seam line kept parallel to the long sides of the specimen.

The specimen were mounted in an Instron Tensile Strength machine under zero load. The width of the clamp was 2.5cm (flat faces) and the gauge length 10cm. The rate of the crosshead travel of the testing machine was adjusted to give a rate of specimen extension of 100mm/min.

The specimen was extended by 30% of its guage length, such extension percentage being chosen because the seams are stretched to relatively low extensions in use, only during the donning of the pressure garment is a relatively high strain applied to the seams in the longitudinal direction.

During testing the crosshead of the tensile strength machine was stopped when the specimen reached 30% extension, and held for 10 seconds, then the crosshead was reversed allowing the specimen to relax for two seconds at its original gauge length. Next the specimen was again stretched to 30% extension and held there for 60 seconds before removing the stretched specimen from the clamps. The sample was then immediately placed on a flat smooth surface, and the length of the stretched seam measured immediately. The measurement of the specimen was recorded again after a period of one minute from the time the specimen was released from strain, and also after 30 minutes relaxation.

From the raw data recorded from the testing, the percentage of recovery is worked out (as shown in Table 4.4), and a comparision of the elasticity and recovery of the four kinds of seams can be made.

Fabric #28432

		Fabric Only	Seam 1				Seam 2				Seam 3				Seam 4			
Thread	Relax Time	(No Seam)	20	28	40	55	20	28	40	55	28	40	55	80	28	40	55	80s.p. 10cm
120	1st sec	99	98	97.5	97.5	97	96.5	96.5	96.5	96.5	96	97.5	98	97	98	98	98	97.5
	1st min	99.5	98.5	98.5	98	97.5	98	98	97.5	97.5	97	98.5	99	98	99	98.5	99	98.5
	30 mins	100	99.5	99	98	98.5	99	98.5	98.5	98	98.5	99	99.5	100	100	99.5	99.5	100
120 & Nylon	1st sec		-	-	-	-	-	-	-	-	-	-	-	-	98.5	98.5	98	97.5
	1st min		-	-	-	-	-	-	-	-	-	-	-	-	99	99	99	98.5
	30 mins		-	-	-	-	-	-	-	-	-	-	-	-	100	100	100	99
180	1st sec		98	97.5	97.5	97.5	97.5	97	96.5	96	97.5	97.5	97.5	97	98.5	98	98.5	97.5
	1st min		99	98	98	98	98	97.5	98	97.5	98.5	99	99	98.5	99.5	99	99	98
	30 mins		99.5	99	99	98.5	99	98.5	98.5	98	99.5	100	100	99.5	100	100	99.5	98.5
180 & Nylon	1st sec		-	-	-	-	-	-	-	-	-	-	-	-	98	98.5	98	97.5
	1st min		-	-	-	-	-	-	-	-	-	-	-	-	99.5	99	98.5	98.5
	30 mins		-	-	-	-	-	-	-	-	-	-	-	-	100	100	100	99.5

Table 4.4 The Percentage of Recovery (%) of Different Types of Seams (Stretch 30% Along Seam Direction)

Fabric #25034

		Fabric Only	Seam 1				Seam 2				Seam 3				Seam 4			
Thread	Relax Time	(No Seam)	20	28	40	55	20	28	40	55	28	40	55	80	28	40	55	80s.p. 10cm
120	1st sec	99.5	97.5	97.5	97.5	97.5	97.5	97	96.5	96.5	96.5	97.5	97	98	97.5	98	98	97.5
	1st min	99.8	98.5	98.5	98.5	98.5	98.5	97.5	97.5	97.5	98.5	98.5	98	98.5	98.5	99	99	98.5
	30 mins	100	99.5	99.5	99.5	99	99	98.5	98.5	98	99	99.5	99.5	100	99	100	100	100
120 & Nylon	1st sec		-	-	-	-	-	-	-	-	-	-	-	-	98.5	98.5	98	98.5
	1st min		-	-	-	-	-	-	-	-	-	-	-	-	99.5	99.5	99	99.5
	30 mins		-	-	-	-	-	-	-	-	-	-	-	-	100	100	100	100
180	1st sec		97.5	97.5	97.5	97.5	98	97.5	97	97	97	97	97.5	98	98	98	98.5	98.5
	1st min		98.5	98.5	98.5	98.5	99	98.5	98	98	98.5	98.5	98.5	99	99	99	99.5	99.5
	30 mins		99.5	99.5	99.5	99	99.5	99	99	98.5	99	99.5	99.5	100	100	100	100	100
180 & Nylon	1st sec		-	-	-	-	-	-	-	-	-	-	-	-	98	98.5	97.5	98.5
	1st min		-	-	-	-	-	-	-	-	-	-	-	-	99	99.5	98.5	99
	30 mins		-	-	-	-	-	-	-	-	-	-	-	-	100	100	99.5	100

Table 4.4 The Percentage of Recovery (%) of Different Types of Seams (Stretch 30% Along Seam Direction)

4.6.1.2 Normal to Seam Direction

As most seams in pressure garments are made in the direction perpendicular to the stress direction of the fabric, that means the strain is applied to the seam mainly normal to the seam direction. In order to examine the elasticity and recovery of the seam under strain which is applied perpendicularly to the seam line, a cut-strip test was designed simulating the seam performance in use.

Rectangular fabric specimens were prepared 5cm x 10cm with the long side of the specimen parallel to the wales direction of the fabric. The short edges of two fabric specimens were joined together by a seam with 1cm seam allowance.

The specimens were then mounted in an Instron Tensile Strength machine (model 1026) in the way as for test 4.6.1.1. The clamp width of the Instron Tensile Strength machine was 5cm (flat faces), and the tension load cell scale was 5Kg. In all cases the specimens were extended at constant rate of 100mm/min. The gauge length was 4cm.

Similar to the test 4.6.1.1, the specimens were secured in an Instron Tensile Strength machine (model 1026) manually under zero load, and were extended by 100% of their gauge length, maintaining the specimen on the clamp (for 10 seconds) at its full extension, the motion of clamp is reversed until the clamps are returned to their original positions, and the specimen is stretched again to 100% extension. The test specimen is released from the clamp after it is held at the clamp for 60 seconds at its full extension.

Again the specimen is placed on a flat and smooth surface immediatly for recording the measurements. The measurement of the specimen is recorded immediately after it is released from the tensile machine, and after it has relaxed for one minute and 30 minutes.

Table 4.5 shows the results of the elastic recovery of the specimens.

Fabric #28432

		Fabric Only	Seam 1				Seam 2				Seam 3				Seam 4			
Thread	Relax Time	(No Seam)	20	28	40	55	20	28	40	5.5	28	40	55	80	28	40	55	80s.p. 10cm
120	1st sec	97.5	88.8	88.8	88.8	90	93.8	95	95	95	93.8	95	95	96.3	97.5	97.5	97.5	97.5
	1st min	98.8	90	90	91.3	91.3	96.3	96.3	96.3	97.5	95	96.3	96.3	97.5	97.5	98.8	98.8	98.8
	30 mins	100	91.3	91.3	92.5	92.5	97.5	98.8	98.8	98.8	96.3	96.3	97.5	97.5	98.8	98.8	98.8	98.8
120 & Nylon	1st sec		-	-	-	-	-	-	-	-	-	-	-	-	97.5	98.8	98.8	97.5
	1st min		-	-	-	-	-	-	-	-	-	-	-	-	98.8	98.8	98.8	98.8
	30 mins		-	-	-	-	-	-	-	-	-	-	-	-	100	98.8	100	100
180	1st sec		88.8	88.8	88.8	88.8	95	95	95	95	93.8	95	95	96	97.5	97.5	97.5	98.8
	1st min		90	91.3	91.3	91.3	96.3	96.3	97.5	96.3	95	96.3	96.3	97.5	97.5	98.8	98.8	100
	30 mins		91.3	91.3	92.5	92.5	97.5	98.8	98.8	98.8	96.3	96.3	96.3	97.5	98.8	100	98.8	100
180 & Nylon	1st sec		-	-	-	-	-	-	-	-	-	-	-	-	97.5	97.5	97.5	98.8
	1st min		-	-	-	-	-	-	-	-	-	-	-	-	98.8	98.8	98.8	98.8
	30 mins		-	-	-	-	-	-	-	-	-	-	-	-	98.8	100	100	100

Table 4.5 The Percentage of Recovery (%) of Different Types of Seams (Stretch 100% Normal to Seam Direction)

Fabric #25034

		Fabric Only	Seam 1				Seam 2				Seam 3				Seam 4			
Thread	Relax Time	(No Seam)	20	28	40	55	20	28	40	55	28	40	55	80	28	40	55	80s.p. 10cm
120	1st sec	97.5	90	90	90	92.5	93.8	95	95	96.3	93.8	95	96.3	96.3	97.5	97.5	98.8	98.8
	1st min	98.8	91.3	91.3	91.3	93.8	96.3	96.3	96.3	97.5	95	96.3	97.5	97.5	98.8	98.8	98.8	100
	30 mins	100	92.5	92.5	92.5	95	97.5	97.5	98.8	98.8	96.3	97.5	97.5	98.8	98.8	100	100	100
120 & Nylon	1st sec		-	-	-	-	-	-	-	-	-	-	-	-	97.5	97.5	97.5	98.8
	1st min		-	-	-	-	-	-	-	-	-	-	-	-	97.5	98.8	98.8	98.8
	30 mins		-	-	-	-	-	-	-	-	-	-	-	-	98.8	100	100	100
180	1st sec		91.3	91.3	92.5	92.5	95	95	96.3	96.3	95	95	96.3	96.3	97.5	96.3	97.5	98.8
	1st min		92.5	92.5	95	95	96.3	96.3	97.5	97.5	96.3	96.3	97.5	97.5	98.8	97.5	100	100
	30 mins		95	95	97.5	97.5	97.5	98.8	98.8	98.8	97.5	97.5	97.5	98.8	98.8	98.8	100	100
180 & Nylon	1st sec		-	-	-	-	-	-	-	-	-	-	-	-	97.5	97.5	97.5	98.8
	1st min		-	-	-	-	-	-	-	-	-	-	-	-	98.8	100	98.8	100
	30 mins		-	-	-	-	-	-	-	-	-	-	-	-	98.8	100	100	100

Table 4.5 The Percentage of Recovery (%) of Different Types of Seams (Stretch 100% Normal to Seam Direction)

4.6.2 Test Results and Discussion

4.6.2.1 Along Seam Direction

Seam 1 and Seam 2 :

The elastic recovery was more or less the same on the seams sewn on fabric #25034 when the stitch density was changed from 20 s.p.10cm. to 55 s.p.10cm, but it was observed that for fabric #28432; the seam recovery was slightly increased when the stitch density was decreased, this may due to the fact that fabric #28432 was a densely constructed fabric, the seam may recover slightly better if less thread was jammed into the fabric.

The change of thread size did not have significant effect on the stretch and recovery of seams in the two tested fabrics. In general, the two test fabrics responded similarly especially when the stitch density was in the medium range (i.e. 28-40 s.p.10cm).

Seam 3 :

The recovery of this type of seam was fairly good, the test results indicated that the average elastic recovery of most specimen was around 99.5%, and the test results of the two tested fabrics did not show much difference, both the stitch rate and thread sizes showed no or little influence on the stretch recovery of the seams.

Seam 4 :

Theoretically, the use of extensible nylon thread to construct a seam could help to improve the extensibility of the seam, but the test result of both fabrics (shown at Table 4.4) did not show much difference when the looper and covering thread of the seam were changed to nylon thread, this may be because the properties of the covering stitch already had very good extensibility. The elastic recovery of seam was almost 100%, especially when the stretch % for the test was fairly low, therefore the application of nylon thread into the seam had very little effect on the seam extensibility if the stretch applied on the seam is not very high.

For the fabric #28432, it was noted that the recovery of the seam was slightly decreased when the stitch density was increased to 80 s.p.10cm, again this was due to the dense structure of the fabric, when the stitch density is too high, a reverse effect may occur because too much stitch was engaged per unit length of seam.

4.6.2.2. Normal to Seam Direction

Seam 1 (Zig-Zag Lockstitch B.S.304):

Because of the structure of the stitch with needle and bobbin thread interlocking only at the turning points of the zig-zag pattern, it was noted that seam grinning appeared when tension was applied to the seam perpendicularly. The stretch and recovery of the seam was not so good because of the seam grinning effect as well as the seam slippage which occured with this type of seam.

For the two fabrics tested, the elastic recovery slightly improved when the stitch density increased, but the stitch density has no significant effect on the change of seam recovery.

Comparing the recovery of the seam sewn by thread pp120 and pp180, the test results indicate that those constructed with finer threads were slightly better in seam recovery, this was more noticable with the open structured fabric #25034 than with the fabric #28432.

Seam 2 (3-Point Zig-Zag Stitch B.S.308):

This type of seam has no slippage but very little grinning under stress at the normal direction. The seam recovery became better when the specimens were given sufficient time to relax from stretch. Even though the specimens could not recover 100% (as do the specimens without seams) the overall seam recovery of the two tested fabrics was very satisfactory. Most specimens could recover up to 98.8% after being relaxed for 30 minutes from 100% stretch.

Seam 3 (Overlocking Stitch B.S.503):

The test results as shown in Table 4.4 indicated that the elasticity and recovery of the seams was affected by the stitch density, the seam recovery is better when the stitch size becomes smaller. The test results confirm the findings of the seam slippage test that the seam slippage was higher when the stitch density was lower, and thus the seam recovery is worse when the slippage of seam is high.

It was also observed that the thread size has no influence on the stretch and recovery of this type of seam, but the average seam recovery of the fabric #28432 is slightly lower than that of the fabric #25034. This small difference in seam recovery may be caused by the thickness of fabric enclosed within the flat seam formed by the overlocking stitch. As the fabric #28432 is thicker than the fabric #25034, the bulkines of fabric seam allowance enclosed inside the stitch will restrict part of the recovery ability of the seam.

Seam 4 (Covering Stitch B.S.606):

As no seam slippage nor grinning was observed at this type of seam, theoretically, the recovery of the seamed specimen will be similar to that of the fabric specimen without seam (i.e., 100% recovery after 30 minutes relaxation). However, the sewing tension and extensibility of thread have some effect on seam recovery, so that some test specimens only recover 98.8% from stretch. This is considered to be an acceptable level of stretch recovery.

When a nylon thread of greater extension was used to construct the seam, the extensiblity of the seam was improved, the test results showed that most specimens had 100% stretch recovery if the seam was constructed with nylon thread.

4.7 SEAM THICKNESS

In addition to the skin-and-garment interface pressure produced on a patient's body, the thickness of seam may affect the comfort of pressure. Different types of stitches, varying from one to a number of sewing threads, and the stitch construction contribute directly to the thickness of seam. The stitch frequency and the size of sewing thread may also have considerable effect on the seam thickness.

This part of the investigation focused on the thickness of the four types of seams (as listed at section 4.1), and the effect of stitch density and size of sewing thread on seam thickness was also examined. The study is based on the thickness of seam in-use (see Appendix 8 for the diagrams of seam construction).

4.7.1 Method of Test

A thickness gauge with a circular presser foot (of size 10 cm^2) were used for the study. The average thickness of the seams was determined by observing the linear distance that the movable presser foot was displaced from a parallel surface by the seam while under a specified pressure (10 gm/cm^2). The test method is derived from ASTM D-1777. Each measurement was repeated three times, and the average results are listed at Table 4.6.

Fabric #28432

Seam Type	Sewing Thread		Stitch Densities (Stitches Per 10 cm)				
	Needle	Looper/Bobbin	20	28	40	55	80
1	120	120	2.08	2.11	2.1	2.11	-
	180	180	2.01	2.04	2.05	2.08	-
2	120	120	2.1	2.12	2.09	2.14	-
	180	180	2.07	2.05	2.1	2.08	-
3	120	120	-	1.53	1.58	1.6	1.62
	180	180	-	1.44	1.48	1.55	1.58
4	120	120	-	1.9	1.93	2.1	2.14
	120	100 (Nylon)	-	1.8	1.84	1.9	2.05
	180	180	-	1.68	1.74	1.77	1.9
	180	100 (Nylon)	-	1.64	1.73	1.75	1.8

Fabric #25034

Seam Type	Sewing Thread		Stitch Densities (Stitches Per 10 cm)				
	Needle	Looper/Bobbin	20	28	40	55	80
1	120	120	1.72	1.72	1.71	1.72	-
	180	180	1.65	1.69	1.68	1.7	-
2	120	120	1.7	1.74	1.74	1.73	-
	180	180	1.7	1.68	1.68	1.67	-
3	120	120	-	1.35	1.4	1.48	1.52
	180	180	-	1.23	1.32	1.38	1.45
4	120	120	-	1.62	1.74	1.8	1.9
	120	100 (Nylon)	-	1.48	1.58	1.63	1.75
	180	180	-	1.32	1.44	1.56	1.65
	180	100 (Nylon)	-	1.28	1.42	1.53	1.62

Table 4.6 The Thickness of Different Types of Seams in Relation to Stitch Densities and Sewing Thread

4.7.2 Test Results and Discussion

Seam 1 and Seam 2 :

The test results for Seam 1 and Seam 2 range from 2.01cm to 2.14 cm for fabric #28432, and 1.65cm to 1.74cm for fabric #25034. There is not a significant difference in thickness between Seam 1 and Seam 2, both the stitch density and thread denier showed little effect on the seam thickness.

When measuring the seam thickness, the seam allowance for Seam 1 and Seam 2 is turned to one side. That means the construction of a seam composed of 3 plies of fabric (see Appendix 8 for the diagram of seam construction). The thickness of the seam made of fabric #28432 without any stitches is bound to be about 2.15 mm (because the thickness of of single ply of fabric is about 0.72mm), but the average seam thickness of Seam 1 and Seam 2 is only around 2.08mm. The results indicate that the fabric plies became more compact after the stitches were applied to the seam. That means the thickness of Seam 1 and Seam 2 depends mainly on the fabric configuration of the the seam construction, the stitch used for the seam joining is not significant to the thickness of seam.

Seam 3 :

The test result showed that the seam thickness was influenced by the stitch density. For example, when the stitch density of the seam (fabric #25034) was 28 stitches per 10 cm, the seam thickness was 1.36cm, it increased to 1.52mm when the stitch density became 80 stitches per 10 cm.

The seam became thicker when a heavier sewing thread was used. For both fabric tested, the seam thickness increased about 0.04mm - 0.12mm when the size of sewing thread was changed from pp180 to pp120.

The stitch used to join the fabrics was significant to the thickness of seams. For example, the seams of fabric #25034 (sewn by PP120 thread and at density 28 stitches per 10 cm) increase by 23% (0.25mm) in thickness because of the application of stitches to the seam to join the plies of fabric. For the seams of fabric #28432 sewn by the same size of thread and stitch density , the row of stitches only increase by the seam thickness 6% (0.09mm). Due to the difference of thickness between the two fabrics (2-plies of fabric #28432 was about 1.44mm; fabric #25034 was 1.1mm), the % change in seam thickness (caused by the stitch) will become bigger when the fabric to be sewn is thinner.

Seam 4 :

The fabric configuration of Seam 3 and Seam 4 was the same (see Appendix 8), but the average thickness of Seam 4 was higher than Seam 3 when the same size of sewing thread was used. This indicated that the row of stitches on Seam 4 was bulkier than that on Seam 3. The thickness of the seam was affected by the row of stitches used to join the fabric plies. For example, the seams of fabric #25034 (at stitch density 80 s.p. 10cm) increase in thickness by 72% (0.8mm) after the row of stitches was applied to the fabric plies.

Both fabrics tested showed similar behaviour. The seam thickness was influenced by both the stitch density and thread size; the seam became thicker when the stitch density was higher and/or a thicker sewing thread was used on the seam. When a ticket No.100 nylon thread was used to replace the polyester looper and covering thread, the thickness of seam decreased slightly. This happened on the seams sewn by thread PP120 or PP180 at different stitch densities. In order to minimise the bulkiness of the seam, a lower stitch density and finer size nylon thread could be considered for seam sewing.

4.8 EVALUATION OF INTERFACE PRESSURE FOR PRESSURE GARMENTS

The aim of this part of the study focused on the investigation of the possible pressure change on the seamline area, and the effect of the open edges of pressure garments on the interface pressure was also examined.

4.8.1 Interface Pressure at the Seamed Area

As the construction of seams may change the thickness, smoothness and extensibility of the joined areas, the difference in interface pressure between the seamed and unseamed areas of the pressure garments was measured using the Oxford Pressure Monitor MKII.

4.8.1.1 Specimen Preparation :

The specimens of each fabrics (#28432 and #25034) to be tested were prepared in the way similar to those described in section 3.2.2; pressure garments which were made in the form of fabric tubes were cut based on the sizes of the cylindrical tube. Two tube models were selected for the study, their sizes were in circumference 20.7cm and 54cm. The fabric tubes were seamed together by a row of 3-point zig-zag stitches (B.S.308 Seam 2) with seam allowance 1cm. Three sizes of fabric tubes were made for each size of tube model: the size of fabric tubes were 15cm in length and in width 15%, 25% and 35% smaller than the circumferences of the cylindrical tube models.

As the size of stitch has little or no effect on the thickness and rigidity of the seam, it is believed that the change of stitch density and thread size would not cause much change in the interface pressure on the seamed area, therefore, all the test specimens were sewn based on one size of stitch (55 s.p.10cm) and one type of thread (PP120).

The tests were repeated on the other three types of seams (Seam 1, Seam 3 and Seam 4). The stitch density and sewing thread used for all the specimens were the same as for Seam 2.

4.8.1.2 <u>Method of Test</u>:

The test specimens were marked and stretched onto the tube model in the same way as in section 3.2.2.1. Four measuring locations were marked on each specimen, interface pressure between the garment specimen and the tube model were recorded at the four marked locations as described in section 3.2.2.1. Based on the consideration of the pressure garment from a performance-in-use standpoint, the test was carried out with the seam of specimen facing up.

The test results recorded at the four locations of each size of specimen are showed in Appendix 11. For the comparision of the interface pressure at the seamline and the unseamed areas, the data measured at the three different locations (except the reading at the centre of seam) were averaged and the results are listed in Table 4.7.

Fabric #28432

Type of Seam	Size of Tube(cm)	Percentage of Reduction	Seamed Area	Unseamed Area
Seam 1	20.7	15%	21	21.6
		25%	33	33
		35%	42	44.7
	54	15%	8	9.7
		25%	11	12
		35%	18	17.3
Seam 2	20.7	15%	23	23.3
		25%	36	33.7
		35%	46	49.3
	54	15%	10	8.7
		25%	10	13.7
		35%	22	21
Seam 3	20.7	15%	28	23
		25%	40	33.7
		35%	55	48.7
	54	15%	14	9
		25%	19	15.7
		35%	26	21
Seam 4	20.7	15%	30	24
		25%	42	34.3
		35%	57	49
	54	15%	15	8.7
		25%	22	15.3
		35%	28	20.7

Table 4.7 A Comparison of Skin-and-Garment Interface Pressure at the Seamed and Unseamed Area.

Fabric #25034

Type of Seam	Size of Tube(cm)	Percentage of Reduction	Seamed Area	Unseamed Area
Seam 1	20.7	15%	20	20.7
		25%	28	28.7
		35%	36	28.3
	54	15%	8	8.3
		25%	11	12
		35%	15	16.6
Seam 2	20.7	15%	22	22
		25%	32	31.3
		35%	36	41
	54	15%	10	8.7
		25%	12	14.3
		35%	19	17.3
Seam 3	20.7	15%	26	22
		25%	37	31.7
		35%	49	41.6
	54	15%	12	8.6
		25%	18	14
		35%	23	18.3
Seam 4	20.7	15%	28	21.3
		25%	38	31.3
		35%	50	41.7
	54	15%	12	8.3
		25%	17	11
		35%	25	18

Table 4.7 A Comparison of Skin-and-Garment Interface Pressure at the Seamed and Unseamed Area.

4.8.1.3 Test Results and Discussion :

Seam 1 and Seam 2 :

The test results indicated that the interface pressures at the seamed areas and the unseamed areas were very similar, this may be due to the seam allowance being turned out. Thus the seamline could compress on the interface surface without causing any extra thickness.

As the material configuration of Seam 1 and Seam 2 basically is the same, very small the difference in stitch formation between the two types of stitches (B.S.304 and B.S.308) caused little change on interface pressure. It is observed that the interface pressure obtained from Seam 1 on average was slightly lower (only about 2mmHg) than from Seam 2 , this may be due to the grinning of Seam 1 when the specimen was under stress. As explained in section 3.2.2, the measurement of the seamed specimen will become bigger when the zig-zag lockstitch (B.S.304) is stressed open.

The test results obtained from the two sizes of cylindrical tube and both fabrics showed similar behaviour.

Seam 3 and Seam 4 :

It was noted that the interface pressure on the seamed area was in general higher than on the unseamed area, the difference of pressure change most probably was caused by the additional thickness and stiffness of the seam. It is believed that greater pressure change will occur when the stitch formation or seam construction is heavier and/or thicker. The test results clearly showed that the amount of pressure increase at the seamed area of Seam 4 (about 6-8mmHg) was slightly higher than that of the Seam 3 (about 3-6mmHg), this is because the construction of covering stitch (B.S. 605) is more complicated than the overlocking stitch (B.S.504).

During the experiment, it was observed that the range of pressure variations at the seamline of Seam 3 was quite large. If the tension of the overlocking stitch failed to be adjusted properly to let the raw edges of the sewn fabrics lie flatly inside the sheath of stitches, the raw edges of the sewn fabrics may roll up inside the sheath and form a rather bulky ridge along the seamline. In that case, the interface pressure measured from the seamline was much higher (could be up to 10mmHg) than in the non-seamed area. Therefore, special attention is required on stitch adjustment before seaming the Seam 3.

Similar results were observed for the specimens having the three different percentage of reduction (15%, 25%, and 35%). This indicated that the interface pressure increase on the seamed area was not significantly affected by the percentage of reduction. The amount of pressure change caused by the seamline also showed no significant difference between the two sizes of cylindrical tube and between the two fabrics under tested.

4.8.2 Interface Pressure on the Open Edges of Pressure Garments

In order to examine the possible change of interface pressure at the area near the open edges of pressure garments, pressure was measured at the locations 7.5cm, 5cm, 3cm and 1.5cm from the hemline of garments. As the method to finish the raw edges of pressure garments may change the interface pressure on the open edges of pressure garments, it is also the aim of this part of the study to compare the difference in pressure if the raw edges of pressure garment is neatened or finished by a different method.

Besides studying the specimens with raw cut edges, the study was carried out with the hemline of specimens finished by three different methods as stated below: (Diagrams of each method are showed at Appendix 12)

<u>Method A:</u> The cut edges were neatened by a row of overlocking stitches (B.S.504 at density 55 s.p. 10 cm).

<u>Method B:</u> A rubber band (1.5cm in width) was stitched (by stitch B.S.304) at the hemline of the garment.

<u>Method C:</u> The raw edges of the hemline were turned up (1cm) and stitched in position by a row of zig-zag lockstitches (B.S. 304)

4.8.2.1 Specimen Preparation :

As the fabric compression near the open edges of pressure edges is not directly related to the type of seam used to sew the garments, it was decided to sew all the specimens by the same type of seam (Seam 2; stitch B.S.308). The method to prepare the specimens is similar to those described in section 3.2.2. Three horizontal lines were marked on the fabric tubes at distances of 7.5cm, 5cm, 3cm and 1.5cm parallel and above the open edges of the garment specimen, and four measuring locations of equal space intervals were marked on each of the circumferential lines. A medium size cylindrical tube (40.4cm circumference) was selected for the study. Three reduced sizes of garment specimens which were 15%, 25%, and 35% smaller than the cylindrical tube were made for the test.

4.8.2.2 Method of Test

The specimens were stretched onto the cylindrical tube, and the interface pressure at the four measuring locations (at the circumferential line 7.5cm above the hem edge) were recorded as in section 3.2.2.1. With the fabric tube remaining on the tube model, the pressure transducer was moved beneath the garment specimen to different sites as already marked on the fabric tubes for pressure recording. Pressures were never measured when the transducer was moving, but were measured with the transducer stationary at each appropriate location for about five minutes to allow the fabric tube specimens to relax completely before the measurements were taken.

With the seam of the garment specimen facing out, the interface pressure was measured twice at each measuring location. The tests were repeated on other sets of garment specimen which were made with the hem edges finished by 'Method A', 'Method B' and 'Method C' as described above.

In order to compare the differences in interface pressure at different distance from the open edge, the data obtained from the four measuring points at the same circumferential line of each specimen was averaged out. Test results are presented at Table 4.8.

Fabric #28432

Method of Neatening Edges	Percentage of Reduction	Distance From the Open Edge			
		7.5cm	5cm	3cm	1.5cm
Raw Edge	15%	13	13.2	11.9	10.5
	25%	18.8	18.6	17.2	15.6
	35%	27.4	27.4	25	22.0
'Method A'	15%	12.5	12.4	11.6	10.0
	25%	19	18.8	17.5	15.6
	35%	27.2	27.4	25.2	22.3
'Method B'	15%	13.6	13.9	12.2	10.6
	25%	20	20.1	18.1	16.0
	35	26.8	26.8	24.5	21.5
'Method C'	15%	13.8	13.7	12.5	13.6
	25%	19.8	19.5	18.2	20.2
	35%	28	28.2	25.5	28.5

Fabric #25034

Method of Neatening Edges	Percentage of Reduction	Distance From the Open Edge			
		7.5cm	5cm	3cm	1.5cm
Raw Edge	15%	12.4	12.3	11.3	10.2
	25%	18.5	18.8	16.2	15.1
	35%	26.2	26	23.8	21.5
'Method A'	15%	13.2	13	12	9.8
	25%	19.2	19.2	16.8	14.5
	35%	25.8	26	23.5	21.4
'Method B'	15%	13.5	13.4	12	10.1
	25%	19.3	19.2	17.3	16
	35	26	26.4	24.0	20.4
'Method C'	15%	13.2	13.2	11.8	13.4
	25%	18.6	18.5	17	18.5
	35%	25.6	25.3	24	25.8

Table 4.8 The Interface Pressure (mmHg) measured at Different Circumferential Lines From the Open Edges of Pressure Garment.

4.8.2.3 Test Results and Discussion

Specimens of Raw Edges (No Finish on Open Edge):

It was noted that the interface pressure measured at the locations 5cm from the open edges was lower than those measured at 7.5cm from the open edges, and the interface pressure recorded at the locations 3cm and 1.5cm from the edge was much lower than those at the circumference 5cm from the edge. The result clearly showed that the interface pressure started to decrease from a distance of 5cm from the open edges. The amount of pressure loss became higher the closer the location of the pressure measurement was to the open edge.

The three sizes of garment specimen behaved similarly, but the smaller the size of garment (that means higher percentage of reduction), the amount of pressure loss at the open edges was higher. For example, the garments made at 35% reduction lost about 5mmHg when the pressure measurement was recorded at a position 1.5cm from the open edge instead of 7.5cm from the open edge, but the garments made of 15% reduction lost only about 2mmHg. The two fabric tested have similar behaviour.

Specimens of Open Edges finished by 'Method A' and by 'Method B' :

The test results of both methods were very similar to those of "Raw Edges". The interface pressure near the specimen edges was lower than those measured at or beyond 5cm from the open edge. This indicated that the use of overlocking or the addition of a rubber band to the open edges of the garment could not prevent the pressure loss caused by the edge effect.

For the 'Method B', even though the rubber band could not prevent the pressure decreasing near the edges of thegarment, the interface pressure measured underneath the rubber band at the edge of the garment behaved differently. The degree of compression on that area depends completely on the size and the type of rubber band used on the garment.

Specimen of Open Edges Finished by 'Method C' :
The interface pressure measured at the circumferential line 3cm above the open edges was slightly lower (about 2mmHg) than those measured at the locations 5cm and 7.5cm from the edges, but the test results obtained at the locations 1.5cm, 5cm and 7.5cm beyond the edges were all similar. This indicated that the use of 'turn-up' at the hem edges of pressure garment was effective in maintaining the interface pressure at the garment edge similar to the pressure obtained from the area at or more than 5cm from the edge, but there is still some pressure loss in the region between the 'turn-up' hem and the circumferential line 5m from the hem edge.

4.9 SUMMARY AND CONCLUSION

4.9.1 Breaking Strength (Under Transverse Loading)

The strength of the four types of seam in both fabrics tested followed the same general pattern, i.e., as the number of stitches per cm increased; so did the seam strength up to a maximum value and then decreased. The latter being due to the effects of jamming and/or of needle damage. The mode of breakage correspondingly changed from predominantly sewing thread breaks to fabric tearing at the seam.

It is obvious that the size of sewing thread plays an important part in seam strength; the stronger the sewing thread, the higher will be the seam strength.

To seam a knitted fabric with a seam efficiency around 80% or above is normally acceptable. All the four types of seam could provide such a seam performance when the stitch density was adjusted up to 55 stitches per 10 cm.

4.9.2 Breaking Extension (Under Longitudinal Loading)

In order to obtain the breaking extension of a seam of 100% or more; for Seam 1 and Seam 2, the stitch density had to be adjusted to 28 stitches per 10 cm or more, and a much higher stitch denstiy (55 stitches per 10 cm or above) was required for Seam 3 and Seam 4.

The breaking extension of all types of seam decreased when the size of sewing thread became smaller. The change of nylon thread (for the looper and covering thread) could help to improve the breaking extension very slightly. The test results of the two fabrics showed very similar behaviour.

4.9.3 Needle Damage

Most of the seams of the two fabrics tested were not affected by the needle damages. Only very few cases have been found with the yarns slightly damaged by the sewing needle. This occurred on the specimens of Seam 4 of fabric #28432 which were sewn with high stitch density (80 stitches per 10 cm) and by a coarser needle (size 14 set point) at a high sewing speed (3000 rev/min).

The needle chosen should be the finest whenever possible, and it should be inspected regularly. A blunt or damaged needle is one of the main causes of fabric damage, particularly on knitted fabrics. The selection of ball-pointed sewing needle and reduction of the sewing speed will help to prevent needle damage. It is also important that all the machine parts in the sewing area should be in good condition; there should be no chips or grooves on the feed dog, throat plate or presser foot which could damage the fabric.

4.9.4 Seam Slippage

Only the seams made of zig-zag lockstitch (B.S.304 Seam 1) and overlocking stitch (B.S.504 Seam 3) were found to have significant slippage when the seam was under strain. They both had similar behaviour i.e. the amount of slippage increased when the amount of seam extension increased. The seam slippage was also affected by the stitch density. It was noted that the lower the stitch density, the higher will be the seam slippage.

Even though slippage was found with Seam 3, in general it is still suitable for use in pressure garments as the garment is generally stretched 5%-30% in use and no or very little slippage was found when the seamed fabric was stretched to such a level of extension. Overall, the amount of slippage is low especially when the stitch density is in the medium range (40-80 s.p. 10cm) or higher.

Seam 1 is the type of seam which gave the greatest slippage. Both seam grinning and slippage occurred because of the structure of the zig-zag stitch. The amount of slippage is acceptable for pressure garments if the extension is not higher than 30 percen, but the slippage may affect the appearance and cause garment failure when the seamed garment is stretched to 100% extension.

It is ideal to use a covering stitch (B.S.605 Seam 4) or 3-point zig-zag stitch (B.S.308 Seam 2) for seaming pressure garments because no slippage was found on such kind of seams. However, the non-extensible seam area may lead to higher stretch in the non-seam area when a seamed garment has to be stretched to a particular total extension. The skin-and-garment interface pressure may be changed if a higher tensile force is required to stretch such seamed garment to a certain size. Therefore the width and rigidity of the seam will influence the garment compression especially if the width of seam is relatively large when compared to circumferential size of the pressure garment.

4.9.5 Elasticity and Recovery

4.9.5.1 Along Seam Direction

To compare the stretch and recovery of seams when stress was applied along the seam direction, it was noted that the Seam 4 was the best in performance, about 80% of the tested specimen could have 100% stretch and recovery fully after being relaxed for a period of 30 minutes.

The overall performance of all test specimens was satisfactory as the average seam recovery was above 90%. This may be because all the specimens were sewn under proper stitch tension and the stretch percentage for the test was fairly low (only 30%).

The two sizes of sewing thread had similar effect on seam recovery, and the change of stitch density gave little influence on the stretch and recovery of seams. In general, the extensibility of seams would be increased if the stitch rate was increased, but an exceptional case was found in Seam 1 and Seam 4 of fabric #28432. Because of the dense fabric construction, the high stitch density (e.g. 55 s.p. 10cm for Seam 1; Seam 2, and 80 s.p. 10cm for Seam 4) may cause the thread to be jammed into the fabric and thus lower the elastic recovery of the seam.

4.9.5.2 Normal to Seam Direction

The stretch and recovery of seams were related to the seam slippage when stress was applied to the seam in the normal direction. The seam of the highest slippage (Seam 1) was also the seam of the lowest seam recovery. The stitch density had some effect on elastic recovery of seams. For example with the Seam 3, the elastic recovery of the seam was better when the stitch size was smaller and the seam slippage was lower.

Seam grinning is also very important to the extensibility and recovery of seams, such as Seam 1 and Seam 2. The recovery of seams became lower when grinning occured under seam extension.

The size of sewing thread in general had no significant effect on the elastic recovery for Seam 2, Seam 3, and Seam 4. The test results indicated that the elastic recovery of the seams remains more or less the same for both sewing threads of different size. This may be because the structure of the stitch was so firm and strong that the seam recovery was determined mainly by the high elastic properties of sewn fabrics rather than the stretchability or size of the thread being used. However, with Seam 1, it was noted that the use of finer sewing thread produced a little improvement on seam recovery. This may be because the use of a coarser or rigid sewing thread led to the more stiff seam structure, and thus will allow the sewn fabric to recover from grinning.

The seam elastic recovery of fabric #25034 was slightly better than the seam of fabric #28432. This could be explained by the open structure of Lycra net fabric being beneficial to stretch recovery of the seam. A seam could have better elastic recovery if it was sewn on a fabric of good stretchability.

4.9.6 Seam Thickness

For Seam 1 and Seam 2, both the stitch density and size of sewing thread showed no significant effect on the seam thickness. The zig-zag stitch (B.S.304 and B.S.308) used for joining the seams did not affect greatly the seam thickness. The thickness of Seam 1 and Seeam 2 depends mainly on the fabric configuration. Because the stitches could make the fabric plies more compact to each other, sometimes the seam with a row of stitches was thinner than the fabric plies without stitching.

For Seam 3 and Seam 4 , the application of stitching on the seam is significant to the seam thickness. A row of covering stitches (B.S.605 sewn by PP120 thread at density 80 s.p.10cm) could increase seam thickness up to 72% in the case of fabric #25034, and the thickness of Seam 3 also increased 23% after the application of a row of overlocking stitches (B.S.504) to the seam. From the results, it is seen that Seam 4 was bulkier than Seam 3.

The seam thickness also influenced by the stitch density and thread size; the seam became thicker when the stitch density was higher and/or a sewing thread of bigger size was used. The test result indicated that the thickness of Seam 4 could be miminized by choosing a lower stitch density and/or using finer nylon thread (for looper and covering thread).

4.9.7 Interface Pressure for Pressure Garments

4.9.7.1 Interface Pressure at the Seamed Area

As the seam allowance of Seam 1 and Seam 2 was turned out and not compressed on the interface surface, the interface pressure recorded from both Seam 1 and Seam 2 showed no significant difference between the seamed area and the unseamed area.

But the extra thickness and stiffness of the seam at Seam 3 and Seam 4 would change the interface pressure. The interface pressure obtained at the seamed area of Seam 3 was about 3-6mmHg higher than the unseamed area, and the amount of interface pressure increase at the seamed area of Seam 4 was 6-8mmHg. The test results indicated that greater pressure change will occur when the stitch formation or seam construction is heavier and/or thicker.

4.9.7.2 Interface Pressure On the Open Edges

It was observed that the interface pressure started to decrease at the point 5cm beyond the open edges and closer to the open edges, the interface pressure became lower. For the specimens with raw edges and those neatened by 'Method A' and 'Method B', the test results were similar. The test results indicated that the method used to neaten the raw edges by overlocking or by adding a rubber band at the open edge could not prevent the loss of interface pressure due to the edge effect. Only the specimens with the 'turn-up' edges (Method 'C') behaved differently. The test results showed that there was still some pressure loss in the region around 3cm from the hem edge, but the 'turn-up' edge was functional in providing an interface pressure similar to those obtained at the area at or beyond 5cm from the edges.

4.9.8 Conclusion

The behaviour of both fabrics tested are very similar. As illustrated in Table 4.1 and 4.2, the seam strength and breaking extension are obviously affected by the stitch density and the size of sewing thread. The seam strength and breaking extension decreases when a lower stitch density or a thinner sewing thread is used and this happens to all the four types of seams tested. It was found that if the stitch density was adjusted to 55 s.p. 10cm, all types of seams (sewn by PP120 or PP180 polyester thread) selected for the test could provide a seam efficiency of around 80% and the breaking extension would be 100% or above. Such seam efficiency and breaking extension are considered normally acceptable for most knitted garments.

Even though the open structure of most Lycra net fabrics is less affected by needle penetration during the sewing process (no significant needle damages is shown from the test), it is always important to use the finest possible needle size, and the use of needles with more rounded points (ball-pointed needle) would be more appropriate for sewing knitted fabrics.

Among the four types of seams under investigation, Seam 1 is the type of seam which gave the greatest seam grinning and slippage. When a seamed garment is stretched to high extension, the slippage will affect the appearance and the performance of a garment. As the stretch and recovery of seams are related to the seam slippage when stress is applied to the seam in the normal direction, Seam 1 is also the seam of the lowest seam recovery.

Seam 1 and Seam 2 have similar thickness and general charateristics except no slippage was found with Seam 2 in the experimental extension range (20-100%). The test results (shown at Table 4.6) indicated that their seam thickness was not significantly affected by either the stitch density or the size of sewing thread. As the seam allowances of both Seam 1 and Seam 2 are turned out in practical use, from the test results as shown in Table 4.7, the interface pressures measured at the seamed area and the non-seamed area are seen to be very similar.

Seam 3 and Seam 4 have the advantage of high extensibility and recovery. Even though slippage was found with the Seam 3, it is still suitable for use in pressure garments as the garment is generally stretched within 30% in use. Within such an extension, almost no slippage was found at the Seam 3. It is favourable to use a covering stitch (Seam 4) for seaming pressure garment because no slippage was found on this kind of seam. However, the non-extensible seam area may lead to a higher stretch on the non-seamed area, thus the width and rigidity of the seam will influence the garment compression especially if the seam is relatively large when compared to the circumferential size of the pressure garment.

The thickness of Seam 3 and Seam 4 was influenced by both the stitch density and thread size. The average thickness of Seam 4 is higher than the Seam 3 when the same size of sewing thread was used. From the test results shown in Table 4.7, it was noted that the interface pressure on the seamed area is in general higher than the unseamed area. The amount of pressure increase at the seamed area of Seam 4 (about 6-8mmHg) was slightly higher than that of the Seam 3 (about 3-6mmHg). This is believed to be due to the fact that the Seam 4 is thicker in construction than the Seam 3.

Examination of the interface pressure at the open edges of tubular pressure garments indicated that there was a loss of interface pressure due to the edge effect. Starting at the region about 5cm from the edge, the interface pressure begins to decrease and the closer to the edges, the lower will be the interface pressure. The garment with raw edges, or neatened by 'Method A' or 'Method B', showed similar behaviour, except those with the 'turn-up' edges (Method C). The test results for the garment with the turn-up edges (at Table 4.8) showed that there is still some pressure loss in the region around 3cm from the hem edge, but the pressure at the edge is similar to those at the area 5cm and greater distances from the edge.

CHAPTER FIVE : WEAR TESTING

5.1 DESIGN OF WEARER TRIALS

The purpose of this part of study is to assess the accuracy and effectiveness of the model designed in a previous chapter (see section 3.4.2 and 3.4.3). Based on the drafting rules developed for the manufacturing of pressure garments; garment samples were made and the expected performance of garments in use was evaluated by conducting wearer trials on patients.

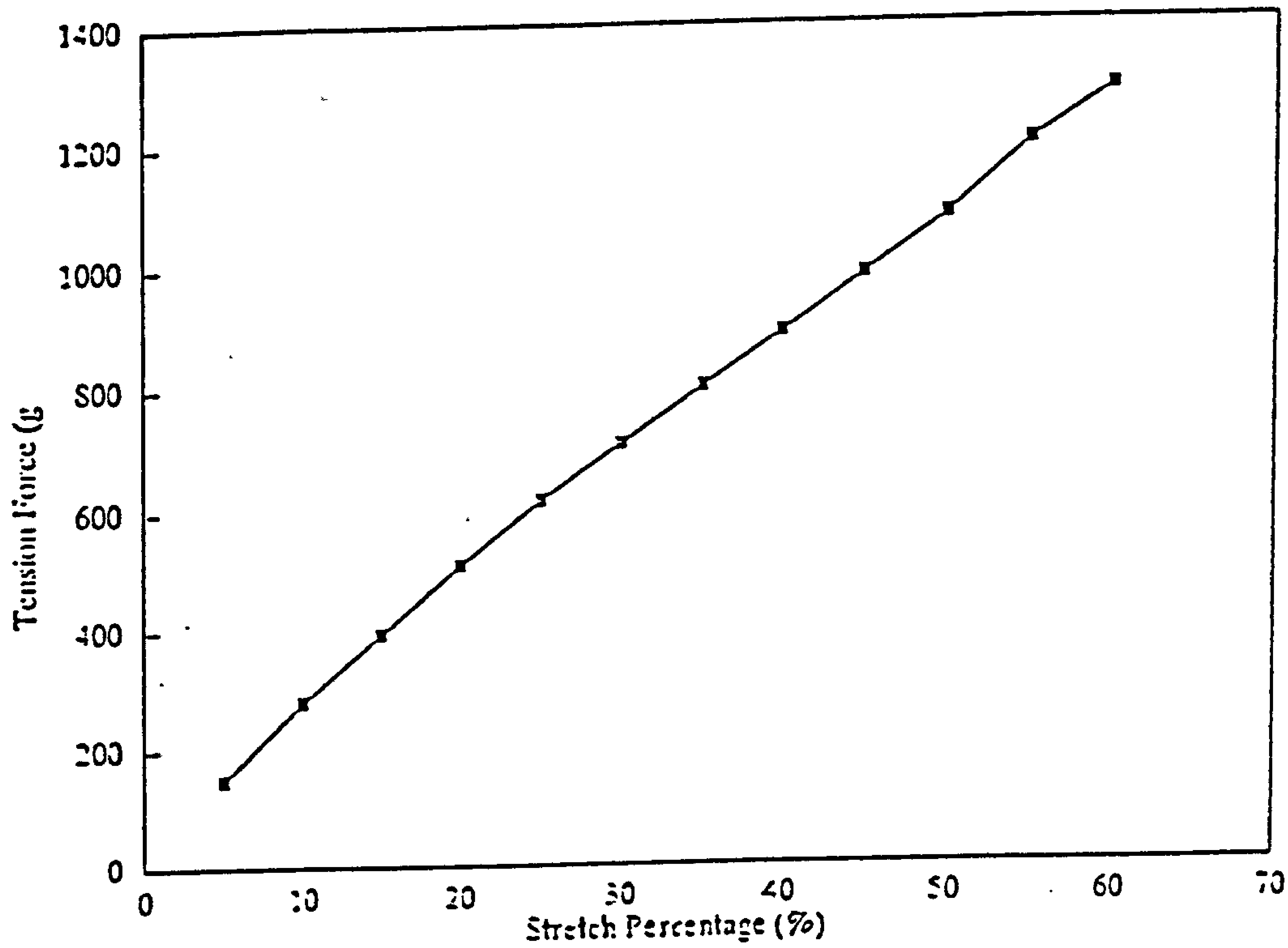
In order to confirm that the model could be applied to other types of Lycra fabric, a different elastic warp knit fabric (#23883) was selected for the study. Details of the fabric specifications are listed as below:

Fabric #23883	: Nylon Sleeknit
Guage	: Rashel warp knitted on 56 guage
Fabric Weight	: 300 gm per sq. meter
Composition	: 78 dtex nylon and 420 dtex elastane
Breaking Load	: 82 kg (lengthway); 95kg (widthway)
Breaking Extension	: 400% (lengthway); 280% (widthway)

The tensile properties of the fabric were studied using an Instron Tensile strength machine (model 1026). The tension force of the fabric under different extension was measured by the cut-strip test. Fabric specimens were cut in size 5cm x 15cm, and the fabric tension was measured when the fabric strips were extended by 5% - 60% (at 5% intervals) in a lengthway direction. The experimental procedures was the same as in section 3.2.1 (See Table 5.1 and Graph 5.1 for the test result).

Stretch Percentage	Fabric #23883
5	150
10	280
15	395
20	510
25	615
30	705
35	800
40	900
45	995
50	1095
55	1200
60	1290

Table 5.1 Fabric Tension (gm. force) of Fabric #23883 at Different Extensions



Graph 5.1 The Load-Extension Curve of Fabric #23883

The wear testing was carried out in two parts. The first part was carried on the same human subject who is involved in the study of section 3.2.3. The second part was carried out on a volunteer patient.

First Part of the Study:

Two sets of samples of pressure garments of the fabric #28432, which aim for providing a garment compression of 20mmHg and 25mmHg, were made to fit the patient's upper limbs and lower limbs. Pressures of 20mmHg and 25mmHg were selected because they are the medium compression ranges most commonly used on patients.

Based on the tensile properties of fabric #23883 (refer to Table 5.1 and Graph 5.1) and the drafting formula developed in section 3.4.2, the size of pressure garments for his lower and upper limbs was worked out (the result is shown at Table 5.2 and 5.3). The samples of pressure garments were produced and fitted on the human subject in the same way as described at section 3.2.3.. After the subject put on the garments, the positions of the garments with respect to the limbs were checked before recording the pressure measurements. Four points at regular spacing were marked at each circumferential line of the garments and the skin-and-garment interface pressure at each of the measuring points were taken by the Oxford Monitor MKII. The data obtained at different locations of the same circumferential position were averaged out for further analysing, and the test was repeated on two more sets of pressure garments. The result of this part of study is presented in Table 5.4.

Circumference of Limbs (cm)	Size of Pressure Garment (cm)	
	20mmHg	25mmHg
59	39.2	35.3
57	38.4	34.7
54	37	33.6
51.4	35.9	32.6
48.5	34.6	31.5
39	29.8	27.4
38.5	29.5	27.2
35.7	27.9	25.8
32	25.8	24
27	22.5	21.2

Table 5.2 The Size of Pressure Garments (circumference in cm) Developed from the Drafting Formula for the Lower Limbs of the Human Subject

Circumference of Limbs (cm)	Size of Pressure Garment (cm)	
	20mmHg	25mmHg
32	25.3	23.6
30.6	24.5	22.8
29	23.5	22
27.2	22.4	21
26.2	21.7	20.4
23.8	20.1	19
20.6	17.8	17
18.7	16.4	15.7

Table 5.3 The Size of Pressure Garments (circumference in cm) Developed from the Drafting Formula for the Upper Limbs of the Human Subject

Circumference of Lower Limbs (cm)	20mmHg		25mmHg	
	Pressure Range	Average Pressure	Pressure Range	Average Pressure
59	15-21	17.5	20-26	23.6
57	15-22	18.5	20-26	24
54	16-21	18.5	21-28	23
51.4	17-23	18.6	21-29	24.5
48.5	16-24	19.6	22-28	24
39	16-25	19	21-27	24
38.5	15-24	21.5	21-28	25
35.7	16-25	22	20-27	23.6
32	17-23	21	22-29	25.5
27	15-24	20.5	21-29	25
Circumference of Upper Limbs (cm)	Pressure Range	Average Pressure	Pressure Range	Average Pressure
32	17-24	19.5	20-27	24
30.6	16-23	19	22-28	23.5
29	18-23	20.5	19-27	25.6
27.2	17-24	19.5	20-28	24.5
26.2	16-25	19.6	21-26	23.6
23.8	18-25	20.5	20-30	26.5
20.6	19-25	21	22-29	25
18.7	18-25	22.5	21-29	25.6

Table 5.4 Skin-and-Garment Interface Pressure (mmHg) recorded from the First Part of Wear-Testing

Second Part of the Study :

A male patient with scars on the knee and thigh participated in the second part of the study. An occupational therapist from a hospital of Hong Kong was invited to make and fit the pressure garments on the patient, and to assess the garment compression suitable to the patient for clinical effectiveness. Two sets of pressure garments were made for the wear testing. One of them was cut and made by the therapist according to her traditional method and the other was made according to the drafting method as described at section 3.2.3. The performance of the two sets of garments was assessed and compared by means of the pressure transducer Oxford Monitor MKII.

According to the advice of the occupational therapist, a pressure garment that can provide a compression 25mmHg would be most suitable for the patient in the wearer trials. Based on her experience with the elastic fabrics and garment making, she decided to cut and make the garment sample by reducing 15% of the circumference measurement of the patient's leg. The details of her drafting method are described at Appendix 9.

When the garment was fitted on the patient, subjective assessment of tension was made by the therapist, and it was found that tension was insufficient around the knee and thigh area. Thus adjustment was made by sewing in about 3/4cm at the seam (that means about 1.5cm was reduced from the circumference of the pressure garment) around that area. The skin-and-garment interface pressure was recorded at the scar area and also five non-scar areas selected at random. In order to avoid the bony part of the knee that may affect the accuracy of the experiment, the scar on the knee area was excluded for the study. The test was repeated three times on three garments.

Another garment sample was constructed according to the drafting rules developed in a previous chapter. The leg of the patient was measured at intervals of 4cm, and the size of pressure garment was worked out based on the tensile properties of the elastic fabric #23883 and the drafting formula (see Appendix 10 for details of the measurement). The skin-and-garment interface pressure was recorded at the scar and non-scar areas for comparison with the traditional method (The result was shown at Table 5.5).

	Traditional Method	Developed Method
Scar Area	17-20mmHg	22-27mmHg
Non-Scar Area	12-16mmHg	20-28mmHg

Table 5.5 Interface Pressure Recorded from the Patient

5.2 RESULTS AND DISCUSSION

The experimental results of the first part of wearer trials (as shown at Table 5.4) indicated that pressure garments constructed under the developed formula can provide the compression close to the expected performance at a reasonable ranges.

The range of variations at the lower limbs was ± 3mmHg, but the range at the upper limbs was slightly bigger (± 5mmHg). As explained in section 3.4.2, there was difficulty in recording measurements on small limbs very accurately; greater error may occur when the circumference of limbs became smaller.

In the second part of the study, the skin-and-garment interface pressure which was recorded from the garment samples made by the traditional method in general was much lower than the expected 25mmHg compression. The results shown in Table 5.6 indicate that the interface pressure at the non-scar area and the scar area was more or less the same; they both lie within the range 13mmHg to 18mmHg. According to the advice of the therapist, additional padding will be added on the scar area to increase the interface pressure if the size pressure garment fails to produce sufficient compression to the patient.

For the other garment samples which were made under the developed drafting rules, the skin-and-garment interface pressure was recorded within the range 20-28mmHg but in general was very close to the expected 25mmHg compression. Similar to the experimental results of the samples made by the traditional method, the pressure recorded at the scar and non-scar area shows no significant difference. This may be because the scar on the patient was not yet hard and raised.

5.3 CONCLUSION AND SUMMARY

The experimental results of both parts of the wear testing indicate that the developed drafting method could help to make a pressure garment to provide a compression according to the requirement of the patient. The drafting method would be suitable on the limbs of a human body except on the bony joints or on the raised scar areas, because the accuracy of the drafting rules may be affected if the interface surface became stiff or irregular.

The compression provided by the pressure garment made by the traditional method was relatively low, even after the adjustment of the size of pressure garment made by the therapist, the interface pressure measured being still far below the expected level of 25mmHg. Even though padding could be used under the pressure garment to increase compression on the skin surface; just like the fitting of pressure garment, the application of padding depends heavily on the experience of the therapist and the outcome compression could not be assessed objectively.

CHAPTER SIX :

CONCLUSION AND RECOMMENDATIONS FOR FURTHER RESEARCH

6.1 SUMMARY AND CONCLUSION

It is generally accepted that the use of pressure therapy is one of the most effective means of preventing and controlling hypertrophic scarring after burn injury. Pressure treatment based principally on the use of pressure garments is widely used in Hong Kong and many other countries. Pressure garments are designed individually for the area of injury. Most pressure garments are made from elastic Lycra fabrics and are made according to the measurements of the individual patients. The manufacture of pressure garments is carried out either commercially or by the staff of medical units in hospitals. The method of manufacturing pressure garments is basically cut-and-sew. The Government hospitals of Hong Kong have been making their own pressure garments within the Occupational Therapy Department since the early 1980's, but it was observed that there has not been much change in the construction method over these years. Many hospitals cut their own pressure garments based on the techniques using an estimated percentage reduction at the pattern stage, and detailed adjustment is made by fitting the garment on the patient, thus alteration of the garments is almost inevitable. The assessment of the garment fitting is basically subjective. It depends on the experience of the occupational therapist and thus variations between therapists may occur.

The intention of this project was to develop a more suitable drafting method for pressure garment construction. The existing problems with garment drafting and subsequent size alteration could be eliminated if rational draft rules for pressure garment construction were formulated.

The study attempted to find out the size of the pressure garment prior to stretch with the aim of exerting even pressure over the circumference of a nearly cylindrical body surface. It was decided to concentrate the investigation on the drafting of pressure garments for the upper and lower limbs of patients. Based on the principle of the Laplace Law and using the fabric tension characteristics. The relation between skin-and-garment interface pressure, fabric tension and fabric curvature were examined by using a simple cylindrical tube model and also the limbs of a human body.

As no commercial fabrics which are specially designed for pressure garments were available for the investigation, two warp knit Lycra fabrics which were of comparatively good serviceability (based on the test results of previous research work) were selected for study. The load-extension properties of the Lycra knit fabrics were determined using an Instron Tensile Strength machine (model 1026).

The instrument used to measure the skin-and-garment interface pressure and the interface pressure between the garment and the cylindrical tube was commercial pressure transducer " Oxford Monitor MKII". It was chosen because the size of its sensing cell is small, thin and flexible, and it is designed to monitor interface pressure within the range of 0-240 mmHg.

Tests to study the effects of garment compression on different curvatures were performed on 63 sets of tubular garment specimens which were made based on the sizes of the cylindrical tube models. The tube models were made in nine sizes, with size ranges similar to the limb sizes of human adults. The size of garment specimen was cut 5%-35% smaller in circumference than the cylindrical tube model. The interface pressures between the garment specimen and the cylindrical tube model were recorded by the Oxford Monitor MKII.

The test results obtained from the cylindrical tube models were correlated to the theory of the Laplace Law. Based on the compression created by the elastic garment specimen of the same size, it was noted that the pressure imposed on the cylindrical tube was reduced when the size of the cylindrical tube was increased; and when the size of garment specimen became smaller (i.e., the reduced percentage of the garment specimen became higher), the pressure induced on the same size of cylindrical tube became higher. Theoretically, the interface pressure approaches zero as the size of the cylindrical tube model increases to infinity. The test results indicated that the interface pressure was below 10mmHg when the size of cylindrical tube was more than 100cm in circumference. The interface pressure induced by different sizes of tube became similar when the size of tube became very large. On the other hand, when the cylindrical tube size was below 10cm in circumference, a small reduction in percentage of the size of the pressure garment would affect the interface pressure significantly.

It was also noted that the interface pressure measured from the cylindrical tube models with different sizes was approximately proportional to the reduced percentage of the pressure garments, with some pressure found which existed on the interfaced surface even when there was no extension on the pressure garments, and this kind of contact pressure was higher when the circumference of the tube was smaller.

As the load-strain relationships measured may vary with different ratio of specimen width and guage length (i.e. aspect ratio), when the size of the limbs was changed, the size of the pressure garment was also changed with different aspect ratio in width and length. Such changes in aspect ratio of the elastic fabric may affect the fabric tension even though the material undergoes the same amount of stretch percentage. Since the change of pressure for different radii of interface surface may be caused by the change of fabric tension, specimen size and aspect ratio were taken into account.

The influence of aspect ratio on the tensile properties of the elastic Lycra fabrics was examined in two ways: by the 'Cut-strip Test' and by the 'Fabric Loop Test'. From the test results of the 'Cut-strip Test', it was observed that there were variations in fabric tension when the aspect ratio of specimens was changed within the experimental range (0.41-0.09), and due to the waisting effect of the elastic fabric under strain, fabric tension decreased when the aspect ratio of the specimen decreased. The results from the 'Fabric Loop Test' showed that the use of the rotating pin clamp for the testing could minimize the waisting of the tested specimen. Without the effect of waisting on the stretched specimen, tension force per unit width of the specimen at different aspect ratio became fairly constant. It should be noted that the waisting effect rarely appeared on pressure garments in practical use, therefore the aspect ratio of garment size was not a crucial factor to be considered.

The relationships between interface pressure and fabric tension were illustrated by the graphs of Tension / Circumference against Pressure (as shown at Graph 3.11, 3.12). The graph indicated that the pressure was proportional to the tension of the fabric within the experimental range particularly if the pressure fell within the range 5-40mmHg. (It should be noted that pressures greater than 40mmHg will result in adverse effects such as maceration or even paraesthesia and would be unsuitable for used on patients). The graph gave a straight line but not through the origin as would be expected by the theory, as there was residual or contact pressure even when there was zero tension in the fabric, and such a contact pressure varied with the tube circumference.

An equation $T = (A+BP)C$ was derived from the experimental results by regression analysis, where T = fabric tension, P = pressure, C = circumference of tube, A = the intercept, B= the slope of graph. As the values of A and B derived from the equation of both fabrics tested were almost the same, therefore the same constants A and B were used for the calculation.

When the pressure recorded from the upper limbs and lower limbs of a human subject were compared to those derived from the experimental tube models, it was found that the average pressure measured on the lower limbs of the human body was

5% lower than that measured from the cylindrical tube. The average pressure measured on the upper limbs of the human body was much lower (around 10%) than those measured from the tube model. The change in the size of limbs during measuring or upon the compression of pressure garments was most probably the cause of the pressure difference. The percentage of pressure loss was higher when there was greater change of the size of the limbs upon the compression of pressure garments.

Due to the fact that pressures measured on the human body were slightly lower than those obtained on the experimental tube model (i.e., $P_{human} = R\ P_{tube}$, where R = Ratio of the slope of pressure curves between the human and tube model), the pressure value based on the tube model was corrected and the equation became: $T = (A + B\ P_{human} / R)\ C$.

As the ratio of the slope of the pressure curves between the human and tube models was different between the lower and upper limbs, the R of the derived equation was not a constant for different parts of the human body. If the equation was applied for lower limbs, the value of R is 0.95, but in the case of upper limbs, it became 0.9.

Having derived the formula for the prediction of the amount of fabric tension required for a particular size of limb and a particular level of skin-and-garment interface pressure, the amount of fabric stretch (stretch %) required for such fabric compression (gf) was worked out by corelating to the load-extension curves of the elastic fabrics. By converting the stretch percentage of fabric to the percentage of reduction of pressure garment, the relationship between the size of the human limbs and the reduced percentage of the pressure garment at various levels of skin-and-garment interface pressure was found (Table 3.17, 3.18 and Graph 3.19, 3.20). For the convenience of the therapists to use in actual practice, the reduced percentage of pressure garments was further converted into the actual size of pressure garment. Different sets of graphs (Graph 3.21, 3.22) were designed for recommending the correct size of pressure garments to the therapists.

As comments from the patients and occupational therapists indicated that discomfort and defects arose in the seam zone, various seaming methods for the manufacturing of pressure garment were investigated. It was important that the stitch and seams used for sewing pressure garments should be compatible with the fabric being sewn both in strength and extensiblity. They should be neat and tidy, with minimum bulkiness, and cause no irritation on skin nor affect the skin-and-garment interface pressure.

The seaming investigation was carried out on three types of seams which were commonly used on the pressure garments with the addition of a seam made of 3-point zig-zag stitch (B.S.308). The testing encompassed the breaking strength of seams, breaking extension, seam slippage, the elasticity and recovery of seams, and seam thickness. The effects of seams and garment edges on interface pressure were also investigated.

According to the physical tests on the four selected seam samples, it was noted that the seam strength and breaking extension were obviously affected by the stitch density and the size of sewing thread. The seam strength and breaking extension decreased when a lower stitch density or a thinner sewing thread were used. It was discovered that all four types of seams could provide a seam efficiency (around 80%) and breaking extension (100% or above) when the stitch density was adjusted to 55 stitches per 10cm (sewn by PP120 or PP180 polyester thread). Such values of seam efficiency and breaking extension were generally acceptable for most kind of knitted garments.

As the open structure of Lycra net fabrics was less affected by needle penetration during the sewing process, no significant needle damage was observed from the two fabrics tested. However, a few cases had been found with the yarns sligtly damaged by the sewing needle when the fabric #28432 was sewn with high density (80 s.p. 10cm) and by coarser needle (Singer size 14 set-point). In order to overcome or minimize the needle damage problem, the needle size and point type (e.g. ball-point needle) must appropriate for the elastic fabric to be sewn.

Among the four types of seams under investigation, Seam 1 (Zig-zag stitch B.S.304) was the type of seam which gave the greatest seam grinning and slippage. As the stretch and recovery of seams were related to the seam slippage when stress was applied to the seam in the normal direction, Seam 1 was also the seam of the lowest seam recovery.

The general characteristics and thickness of Seam 1 and Seam 2 were similar, except no slippage was found with Seam 2 in the experimental extension range (20-100%). As the seam allowance of both Seam 1 and Seam 2 was turned out in practical use, the test results showed that the interface pressures measured at the seamed area and the non-seamed area were very similar.

Overlock seams which were opened out flat and pressed (Seam 3) are in general much more bulky, particularly when the seam allowances tend to roll inside the sheath of overlock stitches, producing an objectionable ridge in the garment. The bulkiness of the seam depended much on whether the seam could easily be flattened. Therefore the stitch tension must be adjusted properly before seaming the pressure garments.

Both Seam 3 and Seam 4 were strong and have the advantages of high extensibility and recovery, they are favourable to use for seaming pressure garments. One of their minor disadvantages is the considerable bulk of seam, which was proved to affect the interface pressure. From the test results, it was noted that the interface pressure in the seamed area was, in general, higher than in the unseamed area, and the amount of pressure increased at the seamed area of Seam 4 (about 6-8mmHg) was higher than that of Seam 3 (about 3-6mmHg). The interface pressure was affected by the seam thickness. The average thickness of Seam 4 was higher than the Seam 3 when the same size of sewing thread was used, but the thickness of Seam 4 was minimized by choosing a lower stitch density and/or using finer nylon thread (for looper and covering thread).

Examination of the interface pressure at the open edges of the tubular pressure garments revealed that there was a loss of interface pressure due to the edge effect: starting from the region about 5cm from the edge, the interface pressure begins to decrease and, the closer to the edges, the lower was the interface pressure. The garment with raw edges, and those neatened by 'Method A' or 'Method B' showed similar behaviour except that, for those with the 'turn-up' edges (Method C), the pressure at the edge could be maintained similar to those at the area 5cm or beyond 5cm from the edge, but there was still some pressure loss in the region around 3cm from the hem edge.

Having designed and developed the drafting rules for the manufacturing of pressure garments, it was necessary to evaluate the performance of garments in use by conducting wearer trials. The wear testing was carried out in two parts and a different Lycra fabric (#23883) was selected for the study. The first part was carried out on the same human subject who was involved in the previous study of garment compression on human limbs in section 3.2.3. Samples of pressure garments were made for his upper and lower limbs according to the developed drafting formula and the tensile properties of fabric #23883. The second part was carried out on a volunteer patient. Two sets of pressure garments were made for the second part of wear testing: one of them was cut and made by a therapist according to her traditional method (see Appendix 9) and the other was made according to the drafting method developed in this project. The performance of all the garment samples was assessed by means of the Oxford Monitor MKII.

As a result of the investigation, it was concluded that the traditional method which the occupational therapists of Hong Kong used to make the pressure garments could not ensure the expected compression be provided on a patient's body. Since the fitting and assessment of pressure garments was subjective, the method relied on the experience of the therapist. The result of the wear testing showed that the garments made by the traditional method provided a compression much lower than was expected. The developed method could help to make a pressure garment in a correct measurement that could produce the compression required for clinical effectiveness. Even though there was still some variations on the scar or bony area, it is believed that the drafting method is very useful in predicting the size of pressure garment for the human limbs, especially for the making of pressure garments for the prevention of hypertrophic scars. In the case that hypertrophic scars already appeared, the accuracy of the drafting rules may be affected because the raised and stiff structure of the scar may alter the properties of the interface surface.

6.2 RECOMMENDATIONS FOR FURTHER RESEARCH

6.2.1

With the aim of ensuring that therapists produce pressure garments more conveniently and accurately, the present study has established practical design rules to draft and make pressure garments. It was evident that the standardization of the pressure level for best clinical effectiveness of scar treatment was necessary. To make the best use of the present analysis, it was hoped that medical staff could apply the drafting rules in making pressure garments and conducting wear trials in their medical units.

In order to obtain a more reliable set of results, it seemed that a broader research on diffferent elastic fabrics and more human subjects would be benefical.

6.2.2

The traditional methods of measuring body dimension by tapes are slow and time consuming since they reveal details about size but not about shape. Since the limbs or other body parts of humans have a very variable geometry, and a custom-made pressure garment is essential to conform precisely and comfortably to the contours of patient's body, advanced measuring tools such as the Loughborough Anthropometric Shadow Scanner (Peter R.M. Jones 1989) [29] may be required.

If this type of equipment is available, the body shape as well as the size of patient can be recorded more accurately and efficiently, and the data of measurement could be used for subsequent Computer Aided Design (CAD) in garment making.

It is the ideal case to have a production unit tied up with the scanner of a computerised system. Having the draft rules of pressure garments all set into a computer program, the pattern drafting of a pressure garment could be done by computer automatically when the size and shape information are transferred from the scanner. Additionally, the computer system could connect with pattern marking, pattern and cloth cutting process, and/or other production units which will tailor a garment to fit an individual patient.

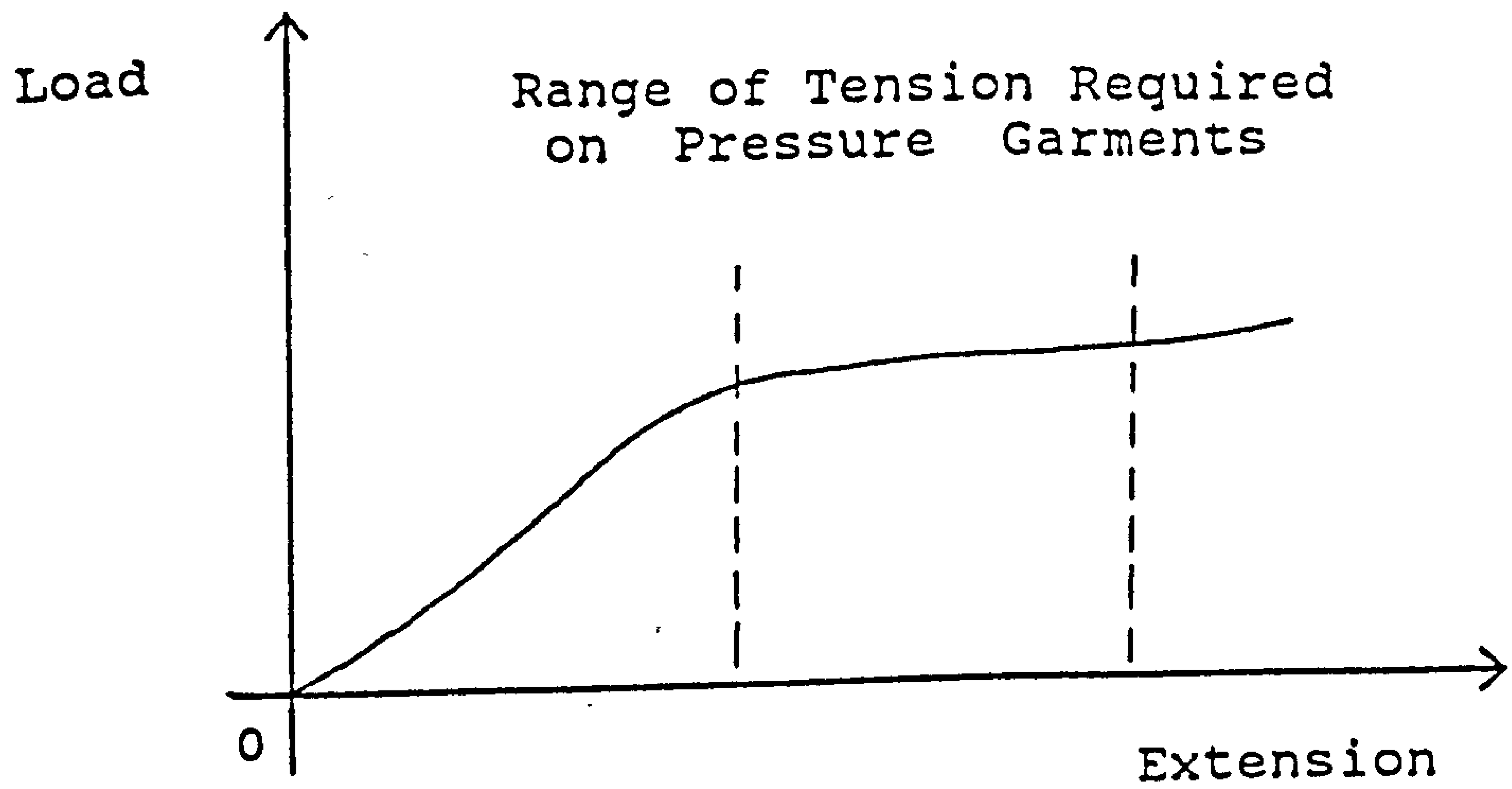
6.2.3

The actual pressure on the skin surface depends upon the biomechanics of superficial body tissue and other anatomical factors. If it is required to estimate the interface pressure on different part of a human body more accurately, the difference between the skin-and-garment interface pressure and the model-and-garment interface pressure (i.e., the ratio 'R' on the drafting formulae as described at Section 3.4.2) should be examined for different points on the human body.

6.2.4

The present work studied skin-and-garment interface pressure in a static state, but there are other variables affecting the pressure change. For example, it was noticed that there was a change of skin-and-garment interface pressure when the patient moved or changed his posture. In patients with hypertrophic scars, the raised hypertrophic scar will alter the surface curvature of the skin, and the rigidity of the interface scar surface would affect the skin-and-garment interface pressure. When a measurable shrinkage of the limbs appears due to the garment compression, the prediction of the skin-and-garment interface pressure becomes more difficult.

A long term solution would be the development of a superior elastic fabric which could maintain constant pressure (constant fabric tension) without being affected by small changes in fabric stretch. If there is a elastic fabric with the load-extension properties as the Graph 6.1, the fabric tension would remain more or less the same when there was a change in extension.



Graph. 6.1 The load-extension curve of a superior elastic fabric

6.2.5

The Oxford Monitor MKII proved adequate for most of the work carried out for this project, as the range of interface pressures used on patients is only 20mmHg, 25mmHg, or 30mmHg . Except for the measurement of very small area, such as the fingers or the seam zone, a more accurate pressure monitor of small sensing cells is required for accurate experiment. If possible, a softer and thinner sensing cell to reduce the interference on interface pressure would be more appropriate.

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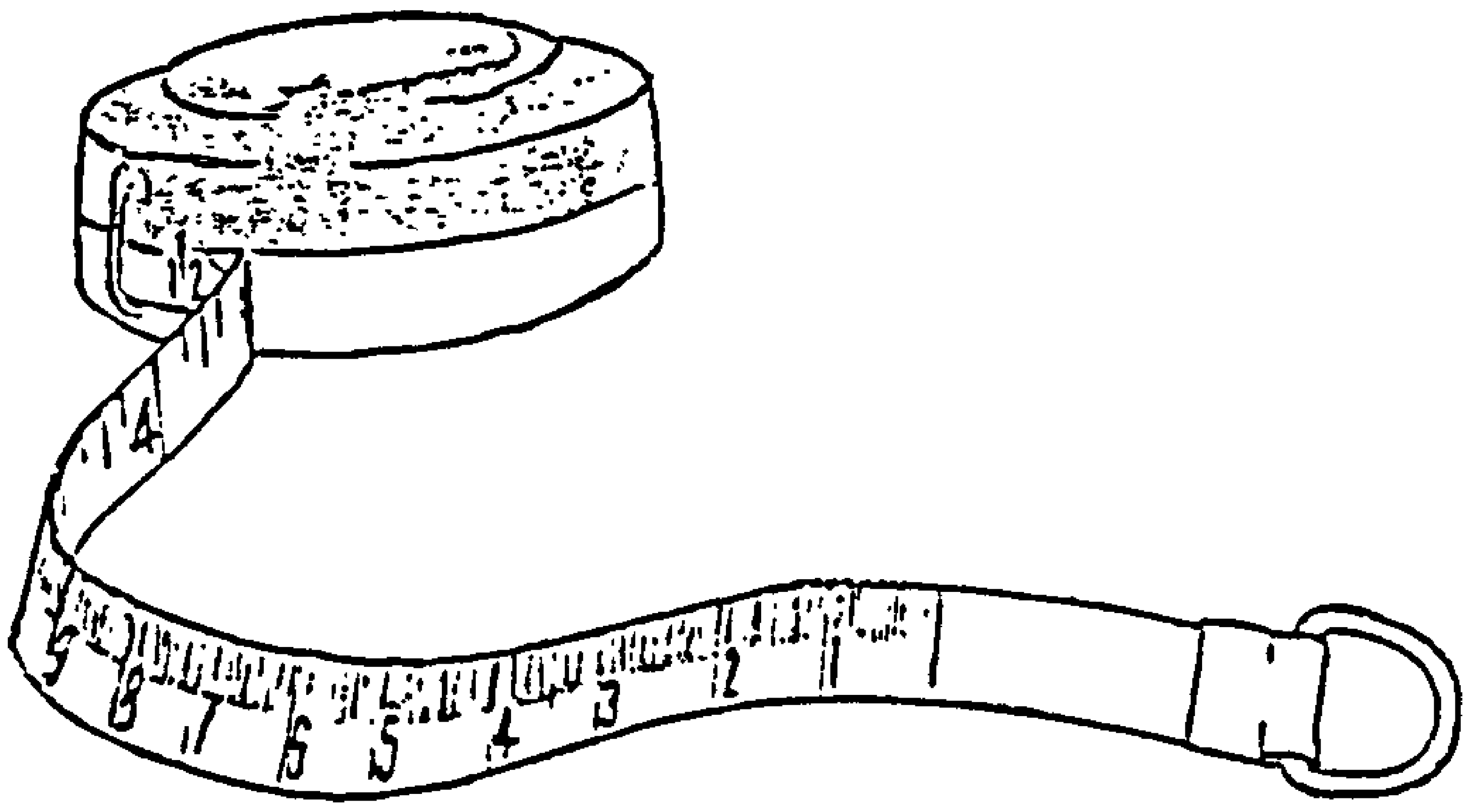

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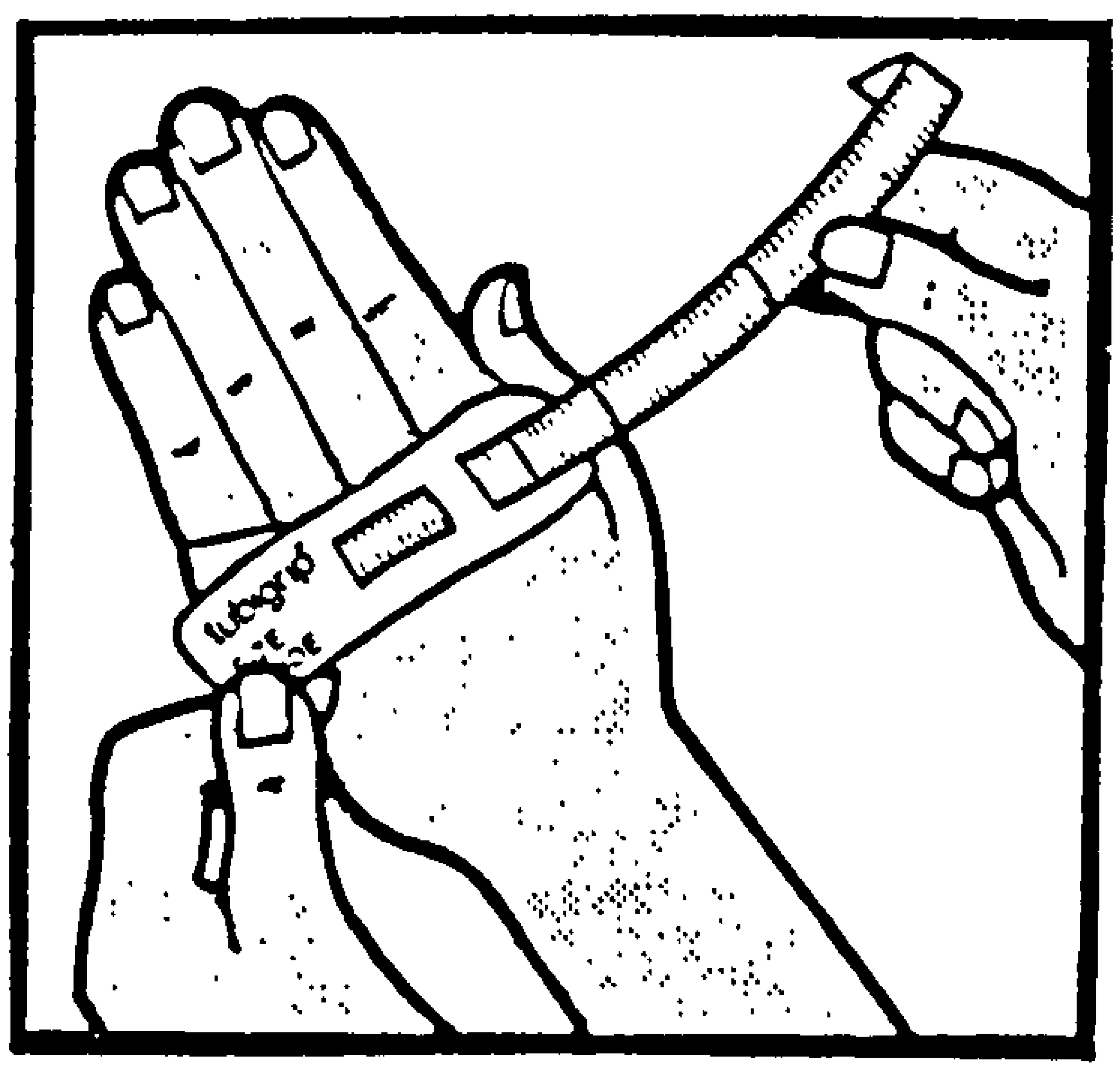


THE SIZES QUOTED ARE IN CENTIMETRES.								
SIZE	1	2	3	4	5	6	7	8
INCHES	6-6½	6½-7	7-7½	7½-8	8-8½	8½-9	9-9½	9½-10
(Cms. approx.)	15-16.5	16.5-17.75	17.75-19	19-20	20-21.5	21.5-22.75	22.75-24	24-25.5

(Ref: Promotional material provided by Seton, U.K.)

Appendix 2

SUPPLIERS

1. Bio-Concepts, Inc., 2430 E Washington St., Phoenix, AZ 85034

2. Elastic Fabric of America, P.O. Box 21986, Greesboro, NG, 27420, U.S.A.

3. Elna Sewing Machines, 11750, Berea Road, Cleveland, OH44111, U.S.A.

4. Isotoner : Aris, 417, 5th Ave., New York NY 10016

5. Jobst, 653, Miami Street, Toledo, OH43605, U.S.A.

6. Mydron Specialties Company, 6894 Halifax Street, San Diego, California 92120, U.S.A.

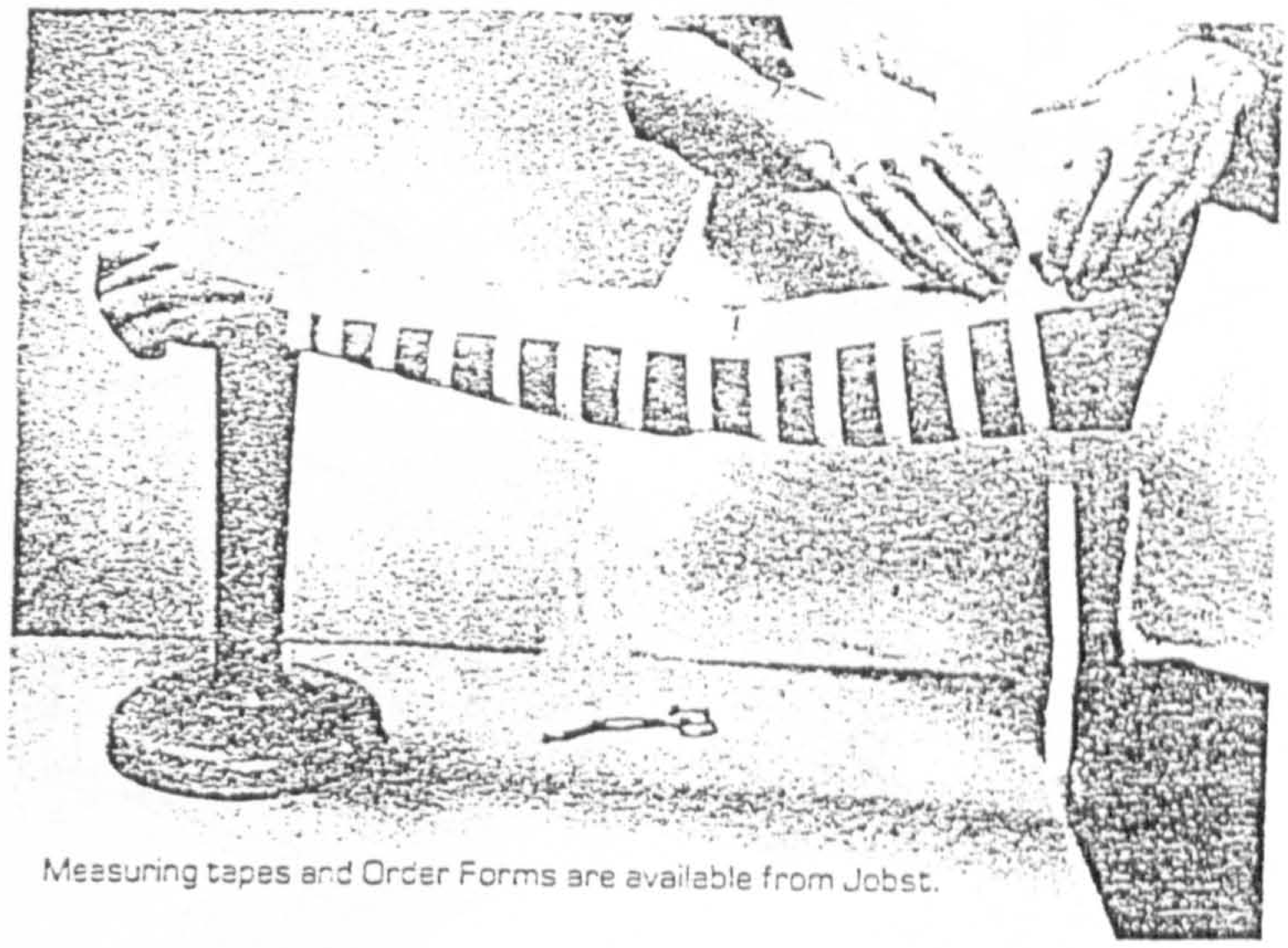
7. Pan Med Ltd., Edison Road, Churchfields, Salisbury, SP2 7NU , U.K.

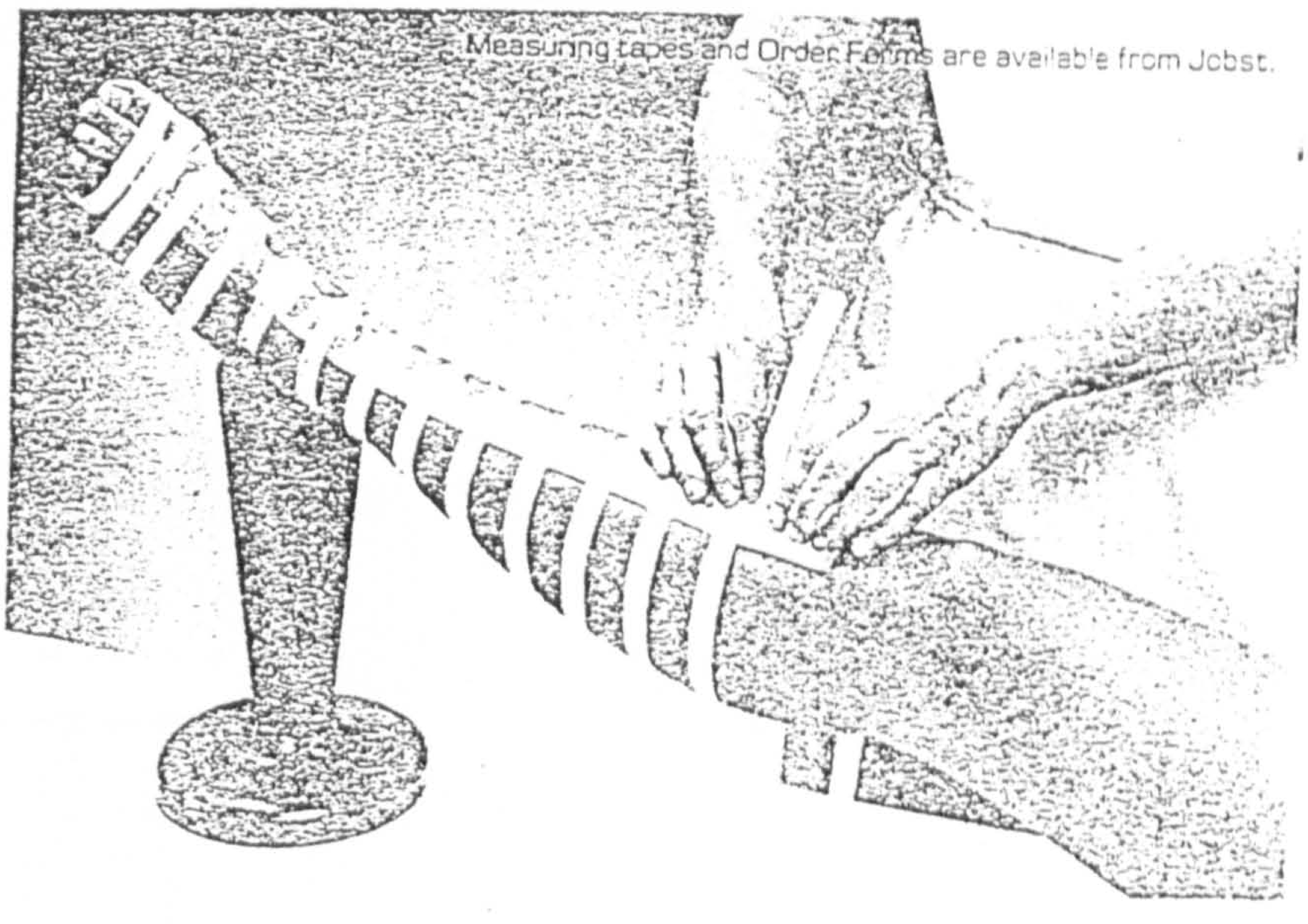
8. Penn International, P.O.Box 8, Wilsthorpe Road, Long Eaton, Nottingham NG10 3LB, U.K.

9. Pohiam Trading Corporation Limited, 9th Floor, Monkok Commercial Bldg., 165, Tung Choi Street, Kowloon, Hong Kong

10. Recovery Garment Centre, 16 Heintzman Street, Toronto, Ontario M6P 2J6, Canada

11. Seton Products Limited, Tubiton House, Oldham O11 3HS England





(Ref: Promotional material provided by Jobst, U.S.A.)

PLEASE MEASURE IN CENTIMETRES

Measurements

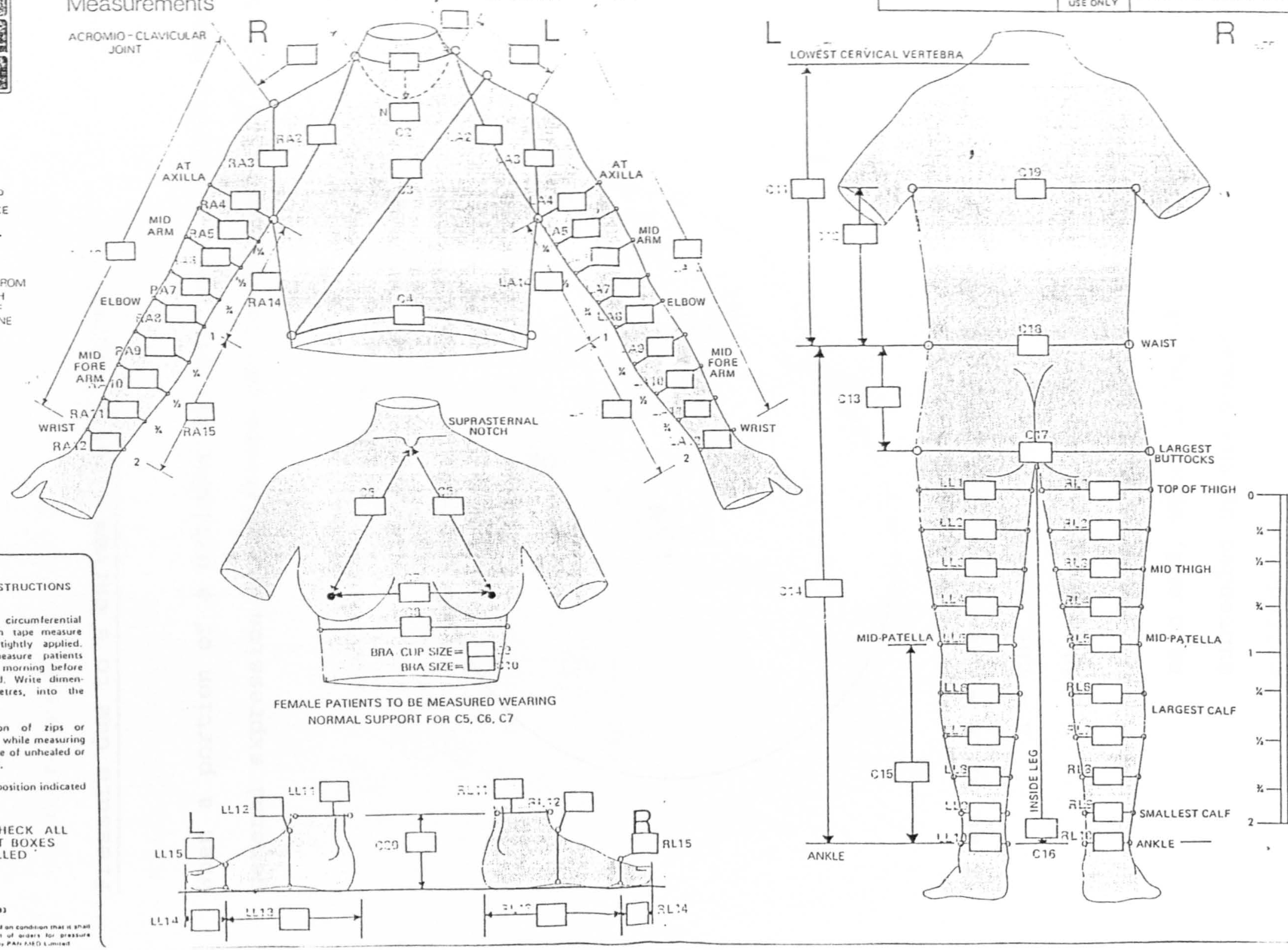
NAME	FOR OFFICE USE ONLY

KEY

CIRCUMFERENCE

LENGTH

N = DISTANCE FROM STERNAL NOTCH TO GARMENT IF LOWER NECKLINE REQUIRED



202

MEASURING INSTRUCTIONS

Make linear and circumferential measurements with tape measure snugly but not tightly applied. When possible measure patients first thing in the morning before oedema is formed. Write dimensions, in centimetres, into the appropriate boxes.

Determine position of zips or velcro, if required, while measuring patient, taking note of unhealed or fragile areas of scar.

Measure limbs in position indicated on the chart.

DOUBLE CHECK ALL RELEVANT BOXES ARE FILLED

Pressure due to a curved elastic fabric

When a portion of a cylinder wrapped with a elastic fabric, a general expression for pressure can be derived from Fig. 1.

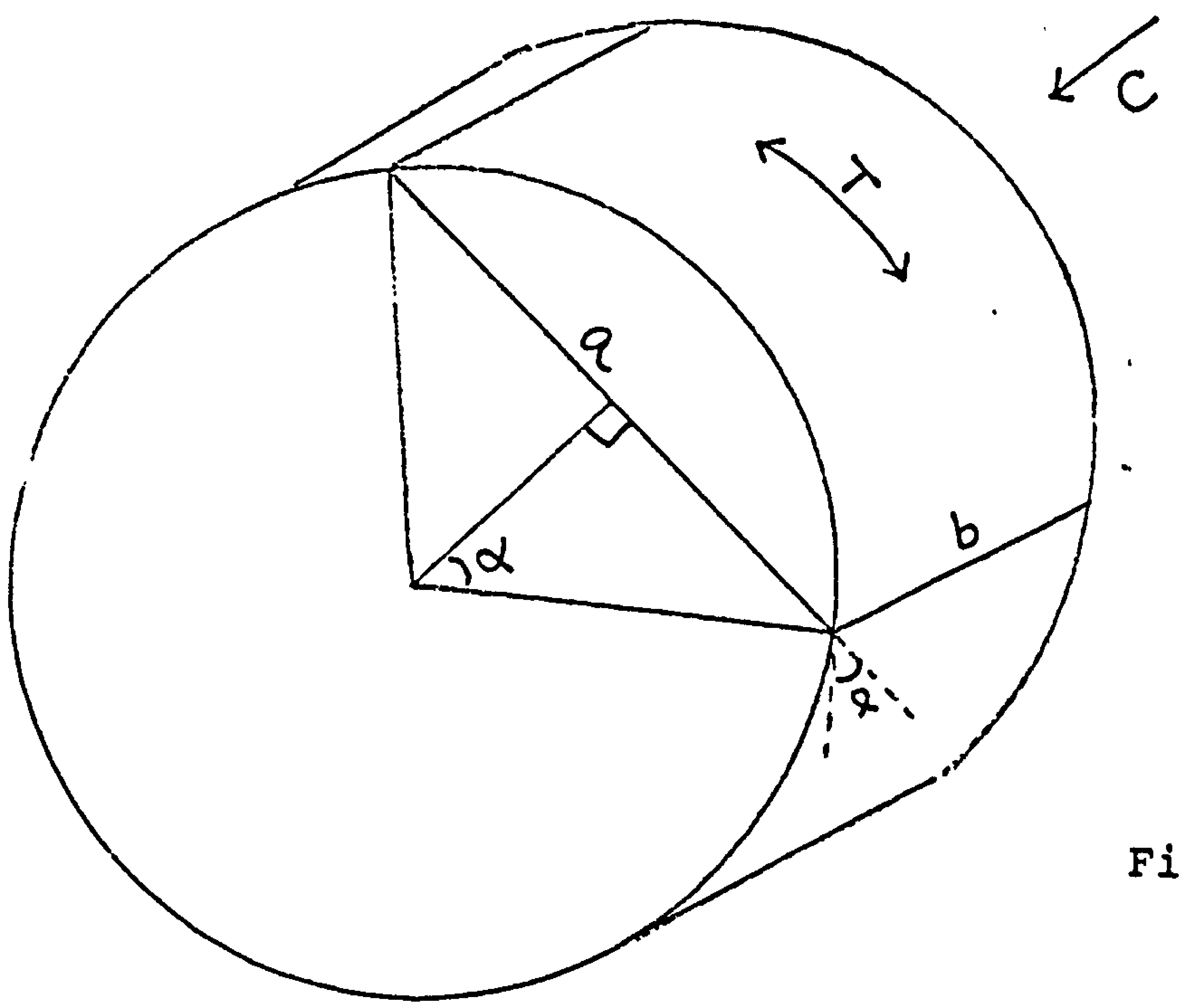


Fig. 1

If we let R = the radius of the cylinder

a = the segment length

b = the length of a portion of the cylinder

and α = the angle between the segment and the tangents at each end, which is equal to the half-angle subtended by the segment at the centre of the cylinder then, when viewed from C, the area of the part of the cylinder bounded by the segment is ab.

The total downwards force on this area due to the fabric tension at each end is 2 bt sinα, where T is the fabric tension per unit width. Since sin α = a/2R, this force is therefore abT/R.

By definition, the pressure P is (force/area), hence

$$P = (abT/R) \times (1/ab) = T/R$$

Similarly, with reference to Fig. 2 which shows a portion of the elastic skin curved in both directions, the total pressure is

$$(Tx/Rx) + (Ty/Ry)$$

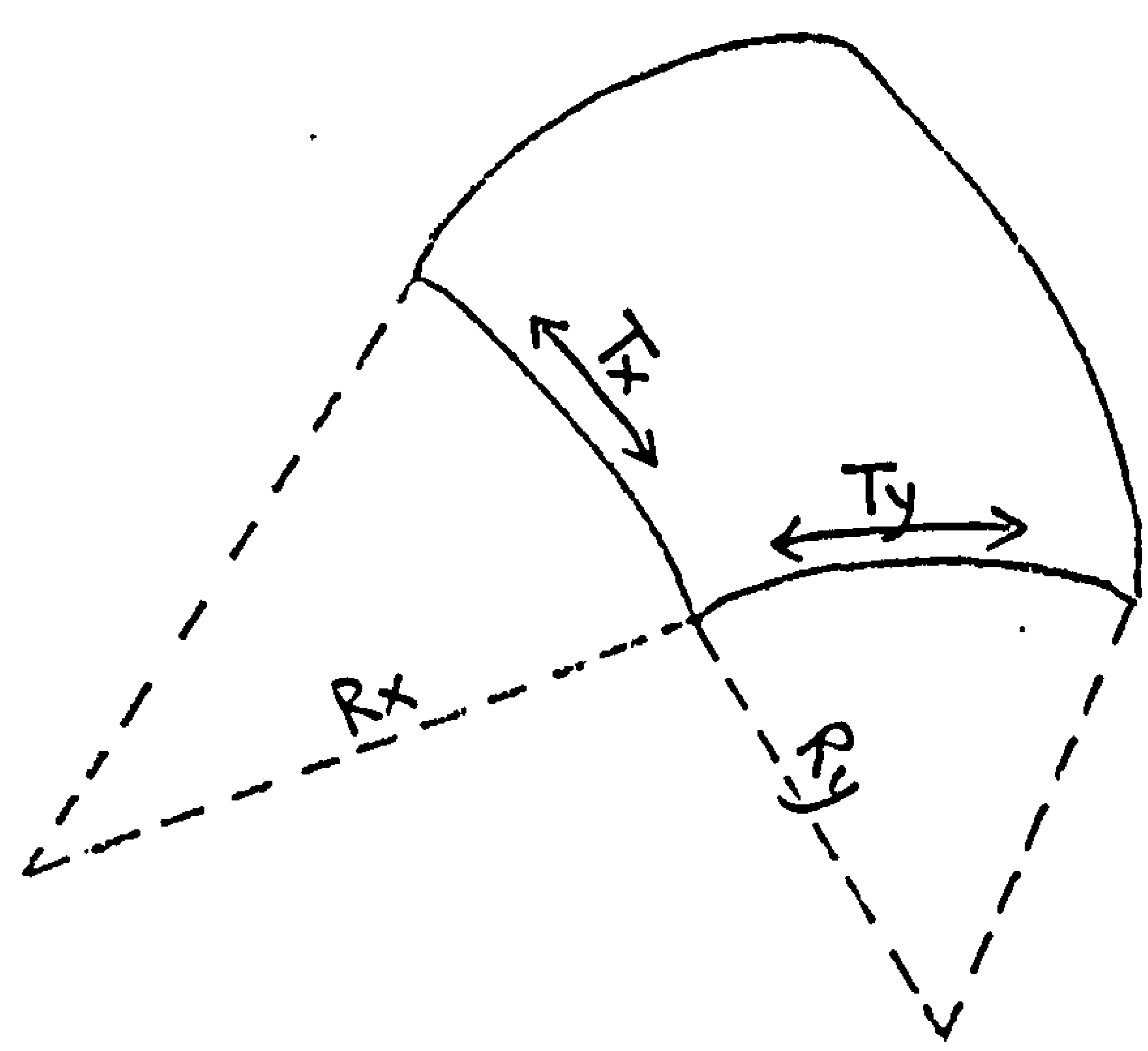


Fig. 2

Fabric #28432 (Pressure recorded from the Experimantal Tube Models)

		Seam Face Up				Seam Face Down			
Size of Tube (cm)	Percentage of Reduction	Center of Seam	Opposite to Seam	90° Left to Seam	90° Right to Seam	Center of Seam	Opposite to Seam	90° Left to Seam	90° Right to Seam
12.3	5%	22	24	20	16	23	20	21	23
	10%	36	35	38	39	38	37	34	32
	15%	43	44	40	37	45	38	39	43
	20%	48	52	50	45	54	48	42	51
	25%	52	56	54	55	59	56	51	58
	30%	55	60	59	63	68	62	57	58
	35%	74	69	73	67	78	65	72	74
16	5%	15	19	15	20	19	14	16	20
	10%	28	23	24	26	29	22	27	28
	15%	28	33	30	29	35	31	32	28
	20%	36	34	39	35	41	33	39	36
	25%	37	43	46	42	46	45	42	40
	30%	53	50	45	49	57	55	46	52
	35%	58	64	58	61	69	60	59	62
20.7	5%	11	9	14	13	14	13	13	11
	10%	17	21	18	20	23	22	16	16
	15%	23	25	24	21	26	24	26	22
	20%	32	30	32	32	35	26	34	30
	25%	36	37	30	34	39	37	32	29
	30%	42	41	44	40	46	40	41	42
	35%	46	47	49	52	54	45	45	50
29.6	5%	8	10	5	10	12	7	9	8
	10%	10	13	12	12	14	14	12	11
	15%	20	17	15	18	21	19	16	19
	20%	21	24	25	18	25	22	18	23
	25%	27	30	26	23	32	23	29	27
	30%	31	31	35	25	37	32	34	28
	35%	36	34	40	36	42	33	34	38

Fabric #28432

		Seam Face Up				Seam Face Down			
Size of Tube (cm)	Percentage of Reduction	Center of Seam	Opposite to Seam	90° Left to Seam	90° Right to Seam	Center of Seam	Opposite to Seam	90° Left to Seam	90° Right to Seam
33.2	5%	7	4	9	6	10	5	9	5
	10%	10	14	11	13	14	12	8	13
	15%	13	15	16	18	19	14	16	17
	20%	17	20	24	20	25	16	20	23
	25%	24	22	25	21	26	23	25	20
	30%	26	27	24	28	32	29	22	27
	35%	36	29	32	32	38	36	34	31
40.4	5%	4	7	6	6	9	3	8	5
	10%	11	6	10	9	12	9	9	8
	15%	11	12	15	11	17	10	16	13
	20%	17	15	14	15	18	12	14	17
	25%	18	18	20	20	22	18	15	21
	30%	23	27	24	25	29	22	27	24
	35%	26	27	30	24	34	26	27	29
54	5%	5	4	2	6	7	3	4	4
	10%	8	7	6	9	11	5	10	7
	15%	10	11	7	8	14	10	5	12
	20%	13	8	12	15	15	11	12	13
	25%	10	15	17	16	20	13	14	16
	30%	17	20	18	18	24	15	22	20
	35%	23	25	20	18	29	20	19	23
76	5%	2	2	3	4	7	3	2	2
	10%	5	4	7	8	9	8	6	8
	15%	10	5	9	10	12	8	8	7
	20%	9	6	8	12	15	7	13	9
	25%	8	9	13	12	15	10	13	10
	30%	15	15	12	16	20	15	11	18
	35%	14	15	19	15	22	18	14	18
81.7	5%	2	1	3	3	5	3	2	4
	10%	3	5	4	7	9	2	8	6
	15%	7	7	6	8	12	6	10	5
	20%	8	9	5	10	14	7	11	6
	25%	8	9	13	10	15	12	11	7
	30%	9	14	14	13	19	10	13	17
	35%	15	14	17	12	20	15	19	14

Fabric #25034

		Seam Face Up				Seam Face Down			
Size of Tube (cm)	Percentage of Reduction	Center of Seam	Opposite to Seam	90° Left to Seam	90° Right to Seam	Center of Seam	Opposite to Seam	90° Left to Seam	90° Right to Seam
12.3	5%	24	18	15	24	25	20	17	22
	10%	34	31	34	37	39	38	33	35
	15%	42	42	41	36	45	44	38	37
	20%	44	47	45	48	52	49	42	46
	25%	52	49	45	55	56	48	56	46
	30%	60	56	62	59	69	59	58	60
	35%	64	72	63	68	75	92	69	67
16	5%	15	19	15	20	20	13	16	18
	10%	23	24	28	27	29	27	26	20
	15%	25	34	29	28	35	26	30	34
	20%	36	29	30	34	38	35	32	38
	25%	36	39	43	38	46	45	42	36
	30%	47	49	44	46	52	49	47	46
	35%	53	58	53	55	62	58	54	54
20.7	5%	16	12	14	11	16	15	12	12
	10%	15	18	19	21	22	18	17	19
	15%	22	20	25	21	26	23	22	21
	20%	28	26	32	30	34	30	28	29
	25%	32	31	33	30	38	31	34	32
	30%	32	37	35	36	41	36	34	35
	35%	36	42	43	38	48	42	42	41
29.6	5%	8	6	4	8	11	7	9	7
	10%	14	14	12	12	16	11	15	12
	15%	16	19	11	15	21	17	15	16
	20%	18	23	20	22	24	20	18	21
	25%	21	26	27	19	28	26	22	22
	30%	24	26	27	29	32	25	26	25
	35%	36	28	32	29	38	34	28	30

Fabric #25034

		Seam Face Up				Seam Face Down			
Size of Tube (cm)	Percentage of Reduction	Center of Seam	Opposite to Seam	90° Left to Seam	90° Right to Seam	Center of Seam	Opposite to Seam	90° Left to Seam	90° Right to Seam
33.2	5%	4	6	7	5	9	8	6	6
	10%	11	11	14	10	14	10	9	12
	15%	14	13	14	16	18	16	14	15
	20%	20	16	21	17	22	19	20	19
	25%	18	23	20	23	27	24	24	19
	30%	23	24	24	26	30	21	25	26
	35%	29	32	28	25	32	31	28	29
40.4	5%	4	5	5	8	7	6	3	7
	10%	8	10	12	7	13	10	11	4
	15%	12	10	15	14	17	12	15	9
	20%	15	13	14	12	18	15	14	16
	25%	18	17	18	19	22	20	16	19
	30%	22	20	26	19	26	25	22	20
	35%	24	27	23	26	31	24	24	27
54	5%	2	3	6	5	6	5	4	3
	10%	8	5	6	8	11	7	6	9
	15%	10	11	7	8	14	9	10	5
	20%	11	10	13	12	17	12	12	11
	25%	12	17	12	14	18	13	14	14
	30%	15	18	19	17	22	17	19	17
	35%	19	17	21	14	25	20	15	20
76	5%	3	1	5	3	5	2	3	3
	10%	4	7	9	6	10	8	7	5
	15%	10	8	7	9	14	4	10	8
	20%	11	10	8	8	15	8	12	10
	25%	12	10	14	10	17	9	9	12
	30%	15	10	12	14	18	14	11	8
	35%	14	15	12	15	20	15	10	14
81.7	5%	2	2	5	3	4	2	3	1
	10%	6	8	7	5	9	4	7	4
	15%	7	7	6	8	11	6	5	7
	20%	9	6	10	9	12	7	5	10
	25%	9	10	8	12	14	10	12	9
	30%	9	7	15	12	15	10	12	12
	35%	10	15	12	14	19	12	13	15

B. Fabric #28432

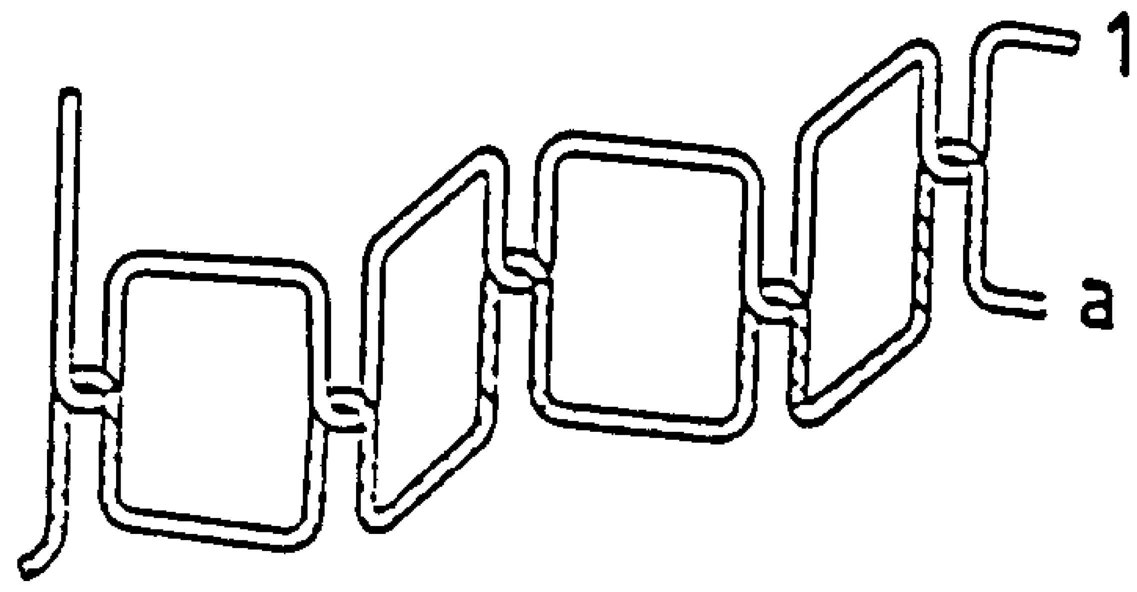
Circumference of Limbs	5%	10%	15%	20%	25%	30%	35%
59.0		4.0	6.3	7.3	10.7	14.0	17.0
57.0		4.5	7.0	8.5	11.3	14.3	17.3
54.0		5.5	8.0	10.0	12.0	15.3	19.7
51.4		6.0	9.0	10.5	13.5	16.3	20.0
48.5		7.0	9.5	11.3	14.5	17.0	21.5
39.0		7.0	11.0	11.0	14.0	20.3	24.0
38.5		7.5	11.3	13.0	16.0	21.3	24.0
35.7		8.0	12.2	15.0	22.0	23.0	25.7
32.0		8.3	13.5	17.3	23.0	28.3	27.2
27.0		10.0	16.3	21.3	24.6	29.7	31.6
32.0	5.0	8.0	10.0	14.4	19.3	25.6	
30.6	5.5	10.3	12.0	14.5	20.5	26.0	
29.0	6.0	10.8	13.3	17.0	22.3	28.2	
27.2	7.5	12.0	13.5	18.0	24.0	29.2	
26.2	7.5	12.0	14.7	17.5	24.8	29.0	
23.8	9.5	12.5	16.0	20.7	27.2	32.1	
20.6	11.0	13.8	17.7	23.9	30.0	34.8	
18.7	12.0	15.0	20.5	26.8	32.5	36.3	

Pressure Measurements Recorded From the Limbs of Human Body

A. Fabric #25034

Circumference of Limbs	5%	10%	15%	20%	25%	30%	35%
59.0		4.0	5.0	7.0	9.0	11.8	14.5
57.0		4.0	5.0	8.0	9.5	12.0	15.0
54.0		5.0	7.0	10.0	10.3	13.5	17.0
51.4		5.5	7.5	10.2	11.0	13.8	17.7
48.5		6.0	7.5	11.0	11.5	15.0	18.5
39.0		6.5	7.0	10.0	13.3	17.7	20.5
38.5		6.5	8.3	10.4	14.0	18.0	20.8
35.7		7.0	10.7	13.3	17.0	19.0	22.7
32.0		7.5	12.9	14.7	19.7	21.0	25.6
27.0		9.0	14.0	18.2	20.7	24.0	28.0
32.0	3.5	7.0	10.0	13.7	17.6	19.6	
30.6	4.0	10.0	11.7	14.7	18.2	21.6	
29.0	5.0	10.2	12.0	16.0	19.3	23.0	
27.2	5.5	11.0	13.0	16.7	19.8	24.6	
26.2	6.0	11.0	12.7	17.0	20.8	26.3	
23.8	7.5	13.0	15.7	18.3	24.3	29.1	
20.6	8.5	14.0	17.3	21.4	26.5	31.2	
18.7	10.0	14.8	18.0	22.0	28.4	33.2	

304



This stitch type is formed with two threads: one needle thread (1) and one bobbin thread (a). A loop of thread 1 is passed through the material from the needle side and is interlaced with thread a on the other side. Thread 1 is pulled back so that the interlacing comes midway between the surfaces of the material being sewn.

The stitch type is the same as 301 except that successive single stitches form a symmetrical zig-zag pattern.

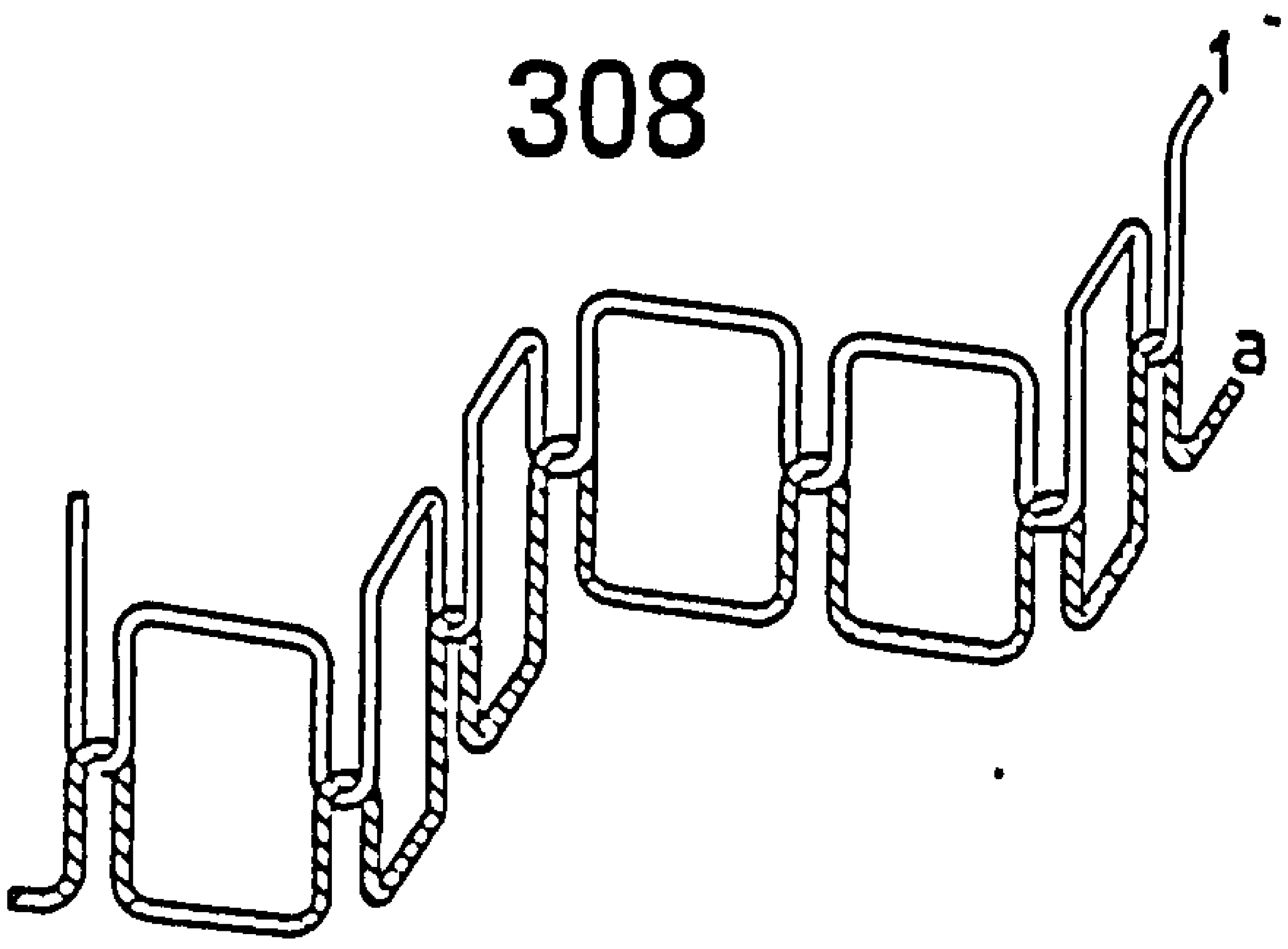
A minimum of two stitches describes this stitch type.

Ce type de point est formé avec deux fils: un fil d'aiguille (1) et un fil de canette (a). Une boucle du fil 1 est passée au travers du matériau par le côté de l'aiguille et est entrelacée avec le fil a de l'autre côté. Le fil 1 est tiré en arrière de manière que l'entrelacement se situe à mi-chemin entre les faces du matériau cousu.

Ce type de point est le même que le type 301, excepté que la suite de points pris un à un forme un motif symétrique en zigzag.

Un minimum de deux points décrit ce type de point.

308



This stitch type is formed with two threads: one needle thread (1) and one bobbin thread (a). A loop of thread 1 is passed through the material from the needle side and is interlaced with thread a on the other side. Thread 1 is pulled back so that the interlacing comes midway between the surfaces of the material.

This stitch type is the same as 301 except that successive pairs of stitches form a symmetrical zig-zag pattern.

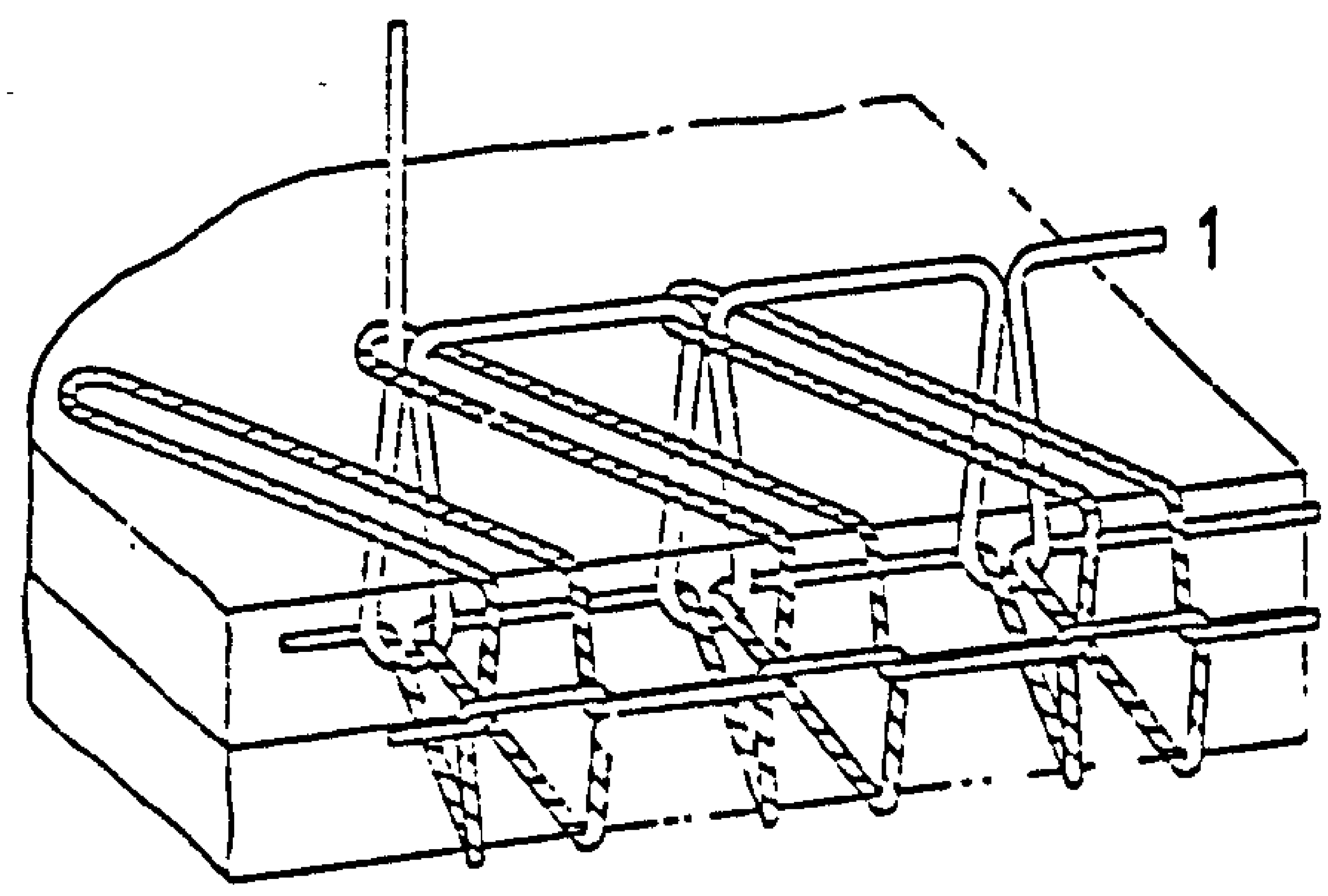
A minimum of four stitches describes this stitch type.

Ce type de point est formé avec deux fils: un fil d'aiguille (1) et un fil de canette (a). Une boucle du fil 1 est passée à travers le matériau par le côté de l'aiguille et est entrelacée avec le fil a sur l'autre côté. Le fil 1 est tiré en arrière de manière que l'entrelacement se trouve à mi-chemin entre les faces du matériau.

Ce type de point est le même que le type 301, excepté que la suite de points pris deux à deux forme un motif symétrique en zigzag.

Un minimum de quatre points décrit ce type de point.

504



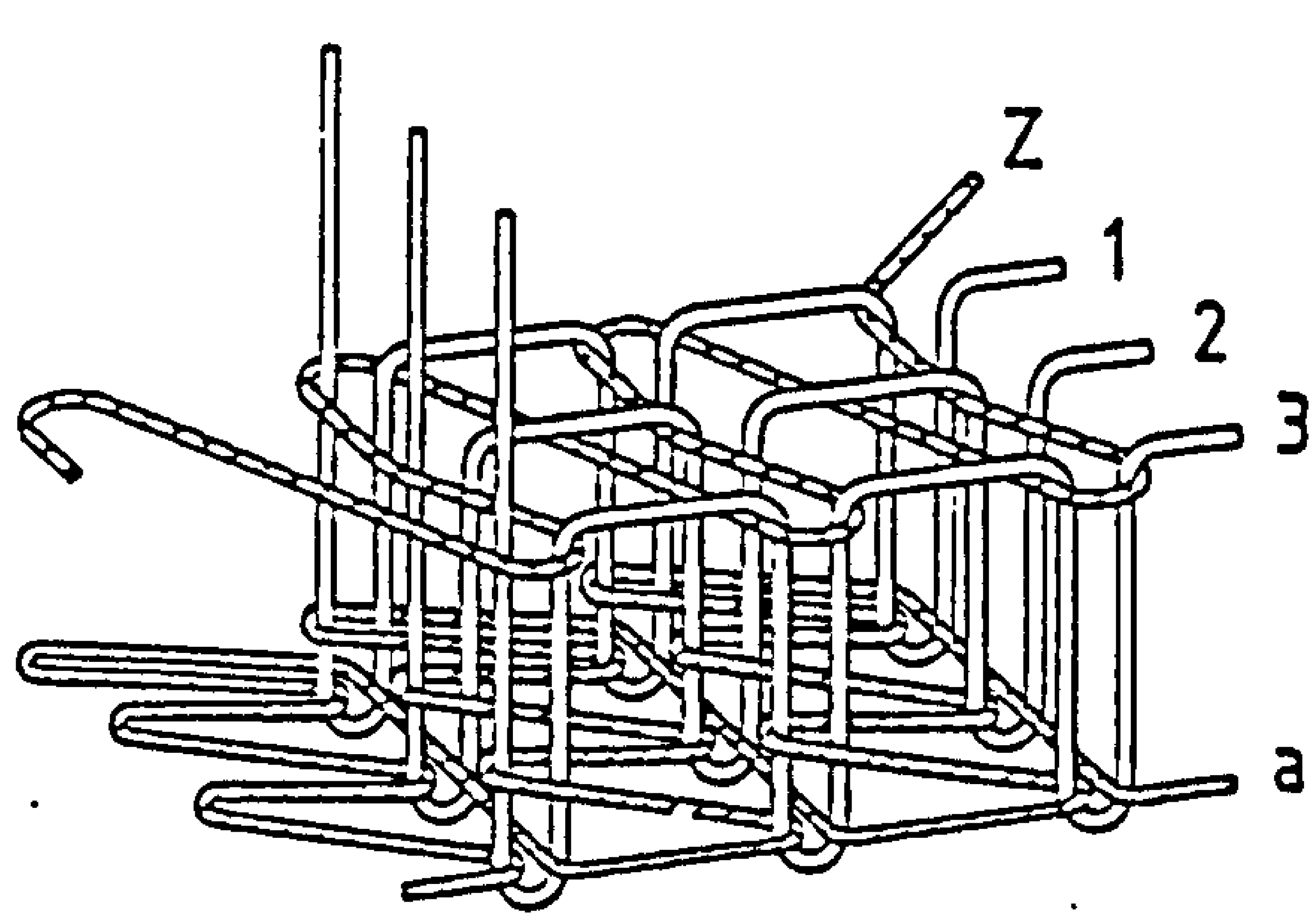
This stitch type is formed with three threads: one needle thread (1) and two looper threads (a and b). A loop of thread 1 is passed through a loop of thread a already laid across the needle side of the material and through the material. The loop of thread 1 is interlooped with a loop of thread b at the point of emergence on the other side of the material. The loop of thread b is brought to the edge of the material where it is interlooped with a second loop of thread a. The loop of thread a is extended from this interlooping to the next point of needle penetration.

A minimum of two stitches describes this stitch type.

Ce type de point est formé avec trois fils: un fil d'aiguille (1) et deux fils de boucleur (a et b). Une boucle du fil 1 est passée à travers une boucle du fil a, déjà posée en travers du matériau côté aiguille, puis à travers le matériau. La boucle du fil 1 est entrebouclée avec une boucle du fil b au point de sortie de l'autre côté du matériau. La boucle du fil b est amenée au bord du matériau, où elle est entrebouclée avec une seconde boucle du fil a. La boucle du fil a est étendue de ce point d'entrebouclage jusqu'au point suivant de pénétration de l'aiguille.

Un minimum de deux points décrit ce type de point.

605

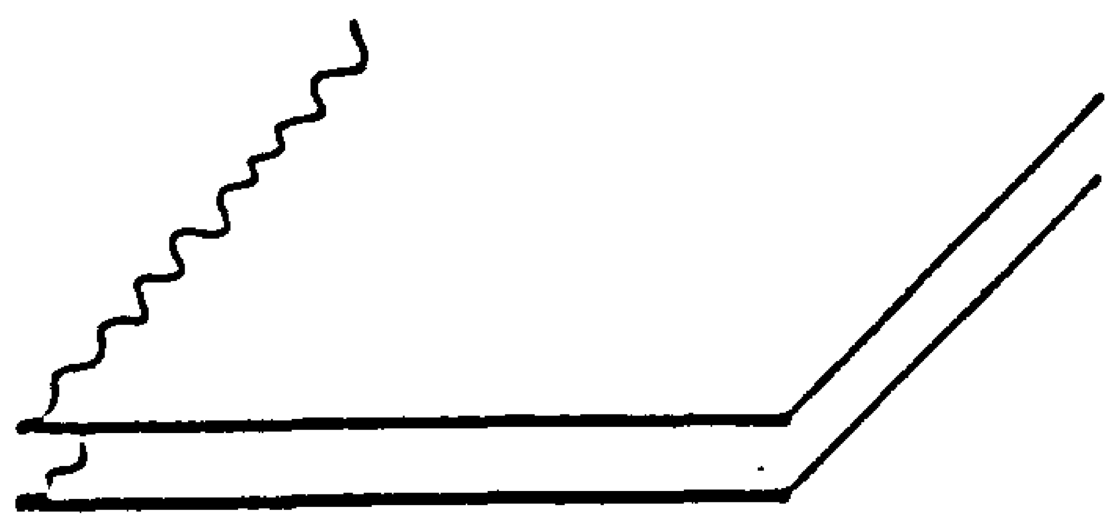
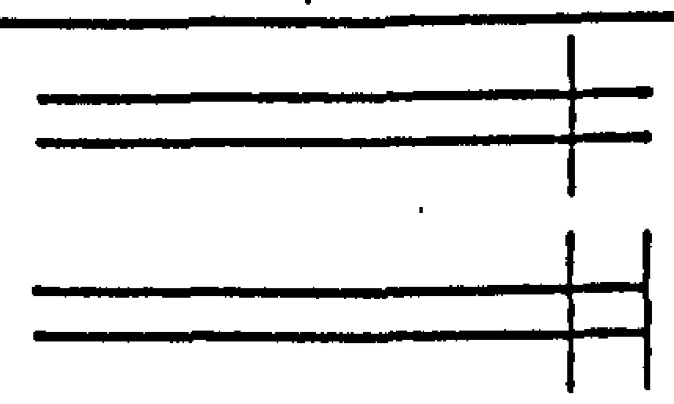
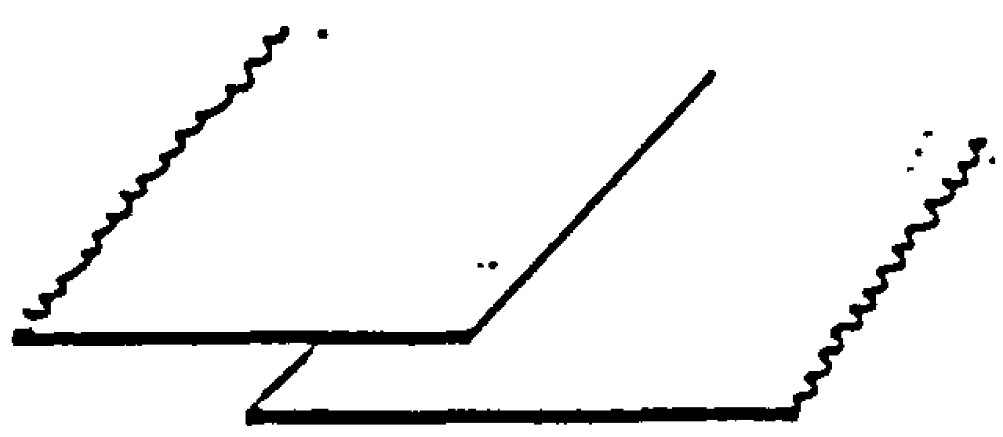
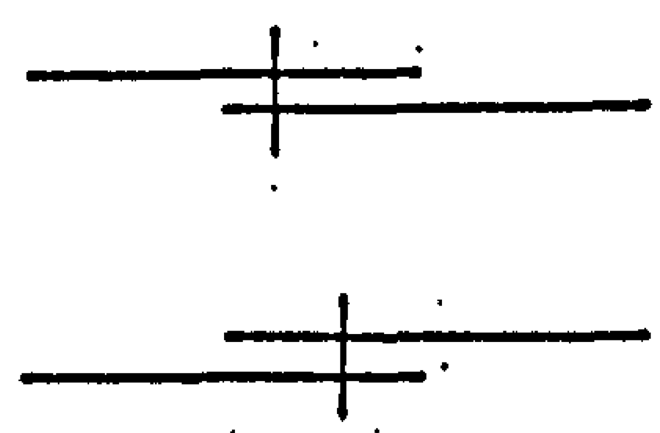


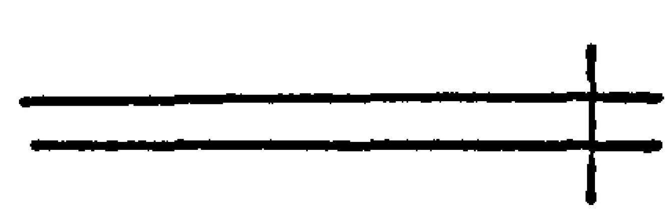
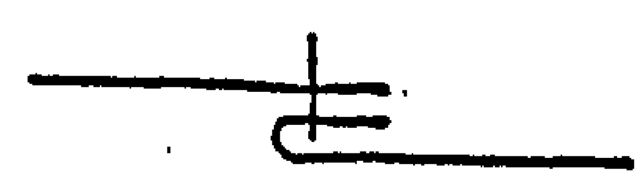
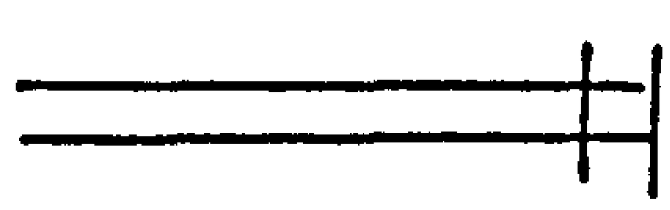
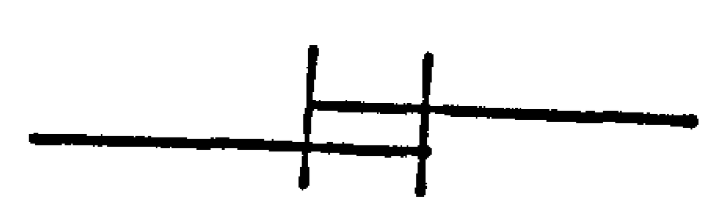
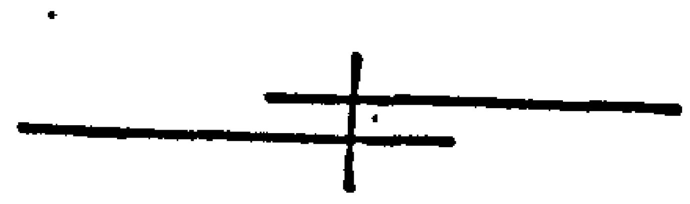
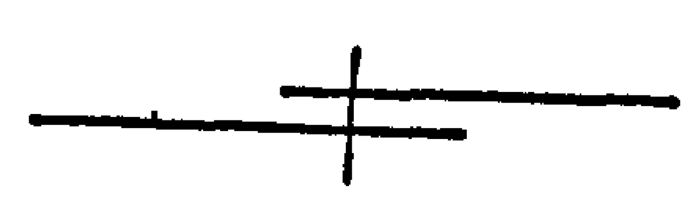
This stitch type is formed with five threads: three needle threads (1, 2 and 3), one looper thread (a) and one cover thread (Z). Loops of threads 1, 2 and 3 are passed through loops of thread Z already laid across the needle side of the material, and then through the material, and through three separate loops of thread a. They are then interlooped with a further loop of thread a and the interloopings are drawn against the material.

A minimum of two stitches describes this stitch type.

Ce type de point est formé avec cinq fils: trois fils d'aiguille (1, 2 et 3), un fil de boucleur (a) et un fil de recouvrement (Z). Les boucles des fils 1, 2 et 3 sont passées à travers les boucles du fil Z, déjà posées en travers du matériau côté aiguille, puis à travers le matériau et à travers trois boucles séparées du fil a. Elles sont ensuite entrebouclées avec une autre boucle du fil a, et les entrebouclages sont serrés contre le matériau.

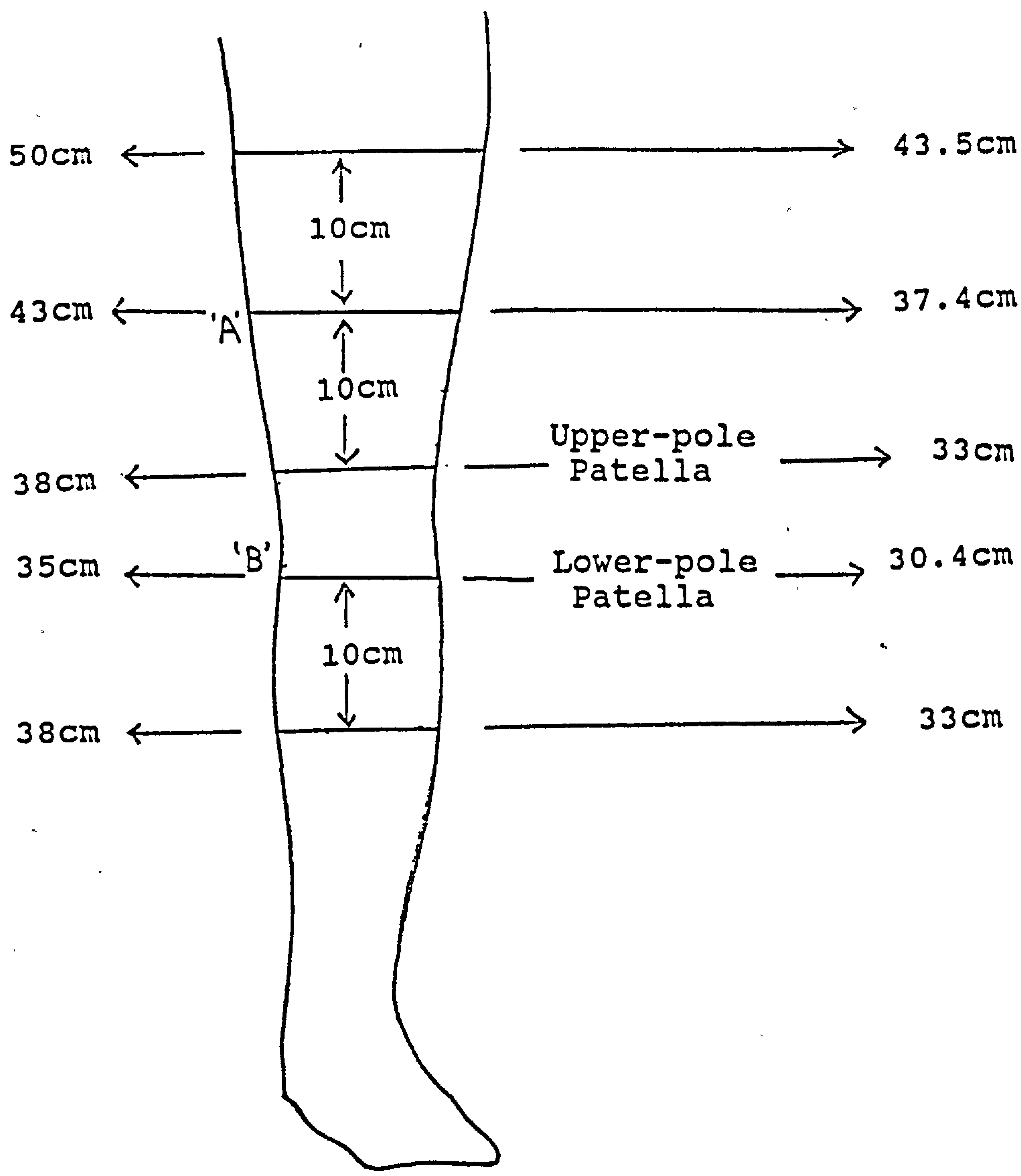
Un minimum de deux points décrit ce type de point.

Material configuration	Location of needle penetration or passage	Numerical designation
1.01 		1.01.01 1.01.02
2.01 		2.01.01 2.01.02

	Seam Joining	Seam In-Use
Seam 1 and Seam 2		
Seam 3		
Seam 4		

Traditonal Method to Draft Pressure Garment for Patient's Leg :

Size of Leg (in circumference) | Size of Garment (before fitting adjustment



Remarks: 1) For a reduction of 15% of the measurement from the circumference of a human's limbs; the method to calculate the size of pressure garment is as following:

Circumference of Leg ÷ 1.15

2) After fitting the pressure garment on the patient, adjustment of the garment was made along the seam area from 'A ' to 'B'.

Developed Method to Draft Pressure Garment for Patient's Leg :

Size of Leg (in circumference)		Size of Pressure Garment (for 25mmHg)
51cm		35.8cm
48cm		34.3cm
46cm		33.4cm
43cm		31.8cm
41cm	Scar Area	30.8cm
38cm		29.2cm
35.5cm (Mid-Patella)		27.8cm
34.5cm		27.3cm
36.2cm		28.2cm
38.6cm		29.6cm
38cm		29.2cm

Remarks: The distance between each measurement was 4cm.

Fabric #28432

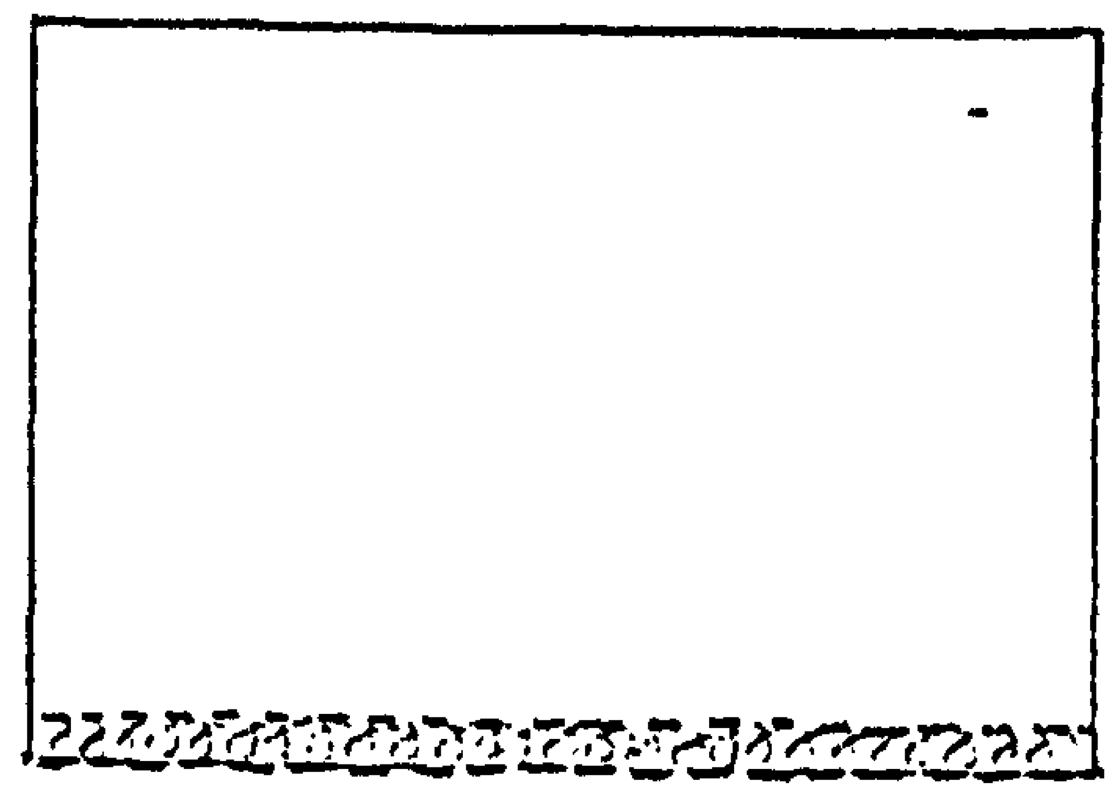
Type of Seam	Size of Tube(cm)	Percentage of Reduction	Centre of Seam	Opposite of Seam	90° Left to Seam	90° Right to Seam
Seam 1	20.7	15%	21	25	20	20
		25%	33	35	32	32
		35%	42	45	45	44
	54	15%	8	7	12	10
		25%	11	14	10	12
		35%	18	17	19	16
Seam 2	20.7	15%	23	25	24	21
		25%	36	37	30	34
		35%	46	47	49	52
	54	15%	10	11	7	8
		25%	10	15	10	16
		35%	22	25	20	18
Seam 3	20.7	15%	28	23	26	20
		25%	40	36	30	35
		35%	55	49	50	47
	54	15%	14	10	6	11
		25%	19	14	15	18
		35%	26	22	18	23
Seam 4	20.7	15%	30	21	24	27
		25%	42	38	35	30
		35%	57	46	49	52
	54	15%	15	7	10	9
		25%	22	16	15	15
		35%	28	20	23	19

Fabric #25034

Type of Seam	Size of Tube(cm)	Percentage of Reduction	Centre of Seam	Opposite of Seam	90° Left to Seam	90° Right to Seam
Seam 1	20.7	15%	20	22	19	21
		25%	28	27	31	28
		35%	36	38	36	41
	54	15%	8	10	6	9
		25%	11	9	14	13
		35%	15	15	19	16
Seam 2	20.7	15%	22	20	25	21
		25%	32	31	33	30
		35%	36	42	43	38
	54	15%	10	11	7	8
		25%	12	17	12	14
		35%	19	17	21	14
Seam 3	20.7	15%	26	20	24	22
		25%	37	33	32	30
		35%	49	41	44	40
	54	15%	12	10	7	9
		25%	18	15	15	12
		35%	23	17	18	20
Seam 4	20.7	15%	28	22	20	22
		25%	38	32	33	29
		35%	50	41	39	45
	54	15%	12	8	9	8
		25%	17	9	11	13
		35%	25	17	18	19

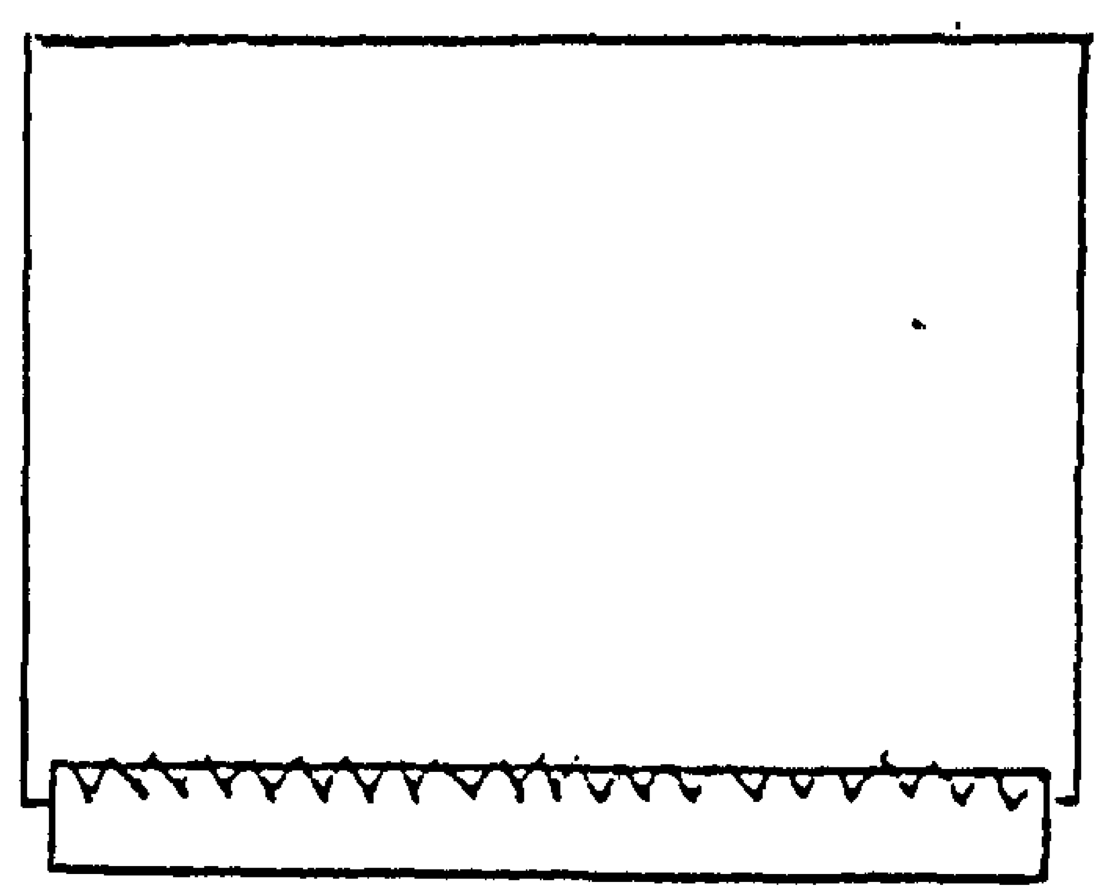
'Method A' :

Overlocking Stitching
neaten the raw edges →



'Method B':

Rubber Band stitched
at the edge by
zig-zag stitching →



'Method C' :

'Turn-up' Hem fixed
by zig-zag stitching →